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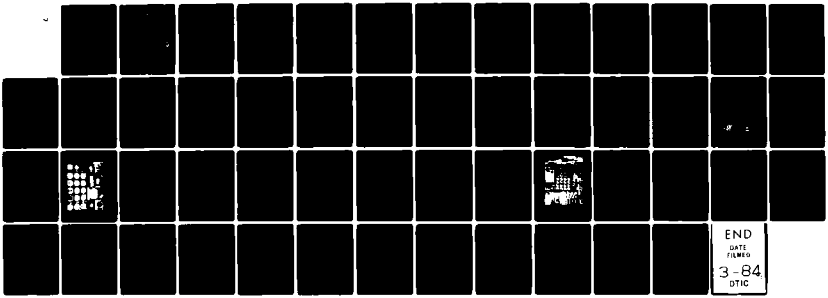

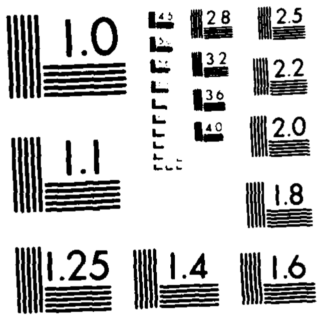

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MECHANICAL ENGINEERING NOTE 393

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SUMMARY

Two Manual Inflight Engine Performance Monitoring Procedures for use on turbo-prop engines have been devised. The first method, which involves relatively complex data reduction, is applicable in its present form only to the Rolls-Royce Dart engine. The second method, requiring only simple arithmetic calculations, may be used on any multi-engined aircraft. The basic principles and operating procedures for both methods are described.

Analysis of inflight engine performance data for the Dart has shown that, even though consistent results in terms of performance trends can be produced, the computational equipment and procedures required to derive the appropriate trend graphs are excessive and are considered not to be warranted or cost effective at present.

With the second method, an analysis of trial data obtained from the Hercules C130–T56 aircraft has shown that effective engine performance monitoring trend plots may be obtained for both torque and fuel flow deviations. The simple data reduction procedures involved allow the relevant analyses to be carried out in flight by a flight engineer or suitable qualified person, thus giving immediate engine trend information for use by air-crew and maintenance personnel on a day-to-day basis.

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CONTENTS

NOTATION

AOAT	Actual outside air temperature (°C)
DA	Static and compressibility corrections for PA (feet)
DAS	Position and compressibility corrections for IAS (knots)
DT	Correction factor for IOAT (°C)
EAS	Equivalent airspeed (knots)
EGT	Exhaust gas temperature (°C)
EOIT	Engine oil inlet temperature (°C)
EPCP70	Engine power check pressure at 70°C (psi)
EPCP100	Engine power check pressure at 100°C (psi)
EPR	Engine pressure ratio
FF	Fuel flow (lb/hr)
FFC	Corrected fuel flow (lb/hr)
FFS	Specification fuel flow (lb/hr)
IAS	Indicated airspeed (knots)
IOAT	Indicated outside air temperature (°C)
LLL	Lower limit line
MCS	Maintenance control section
M	Mach number
N	Engine speed (rpm)
N_1	Engine speed low pressure spool (rpm)
N_2	Engine speed high pressure spool (rpm)
OAT	Outside air temperature (°C)
PA	Pressure altitude (feet)
PAC	Corrected pressure altitude (feet)
p_0	Ambient pressure at altitude PAC (psia)
P_1	Total pressure at inlet to compressor (psia)
PMDTP	Pilots minimum dry torque pressure (psi)
RAME	Combined multiplier for ram air effects and intake efficiency
RPM	Revolutions per minute
RPMC	Corrected revolutions per minute
SHP	Shaft horse power

t_0	Absolute actual outside air temperature (K)
T_1	Total temperature at inlet to compressor (K)
TAS	True airspeed (knots)
TGT	Turbine gas temperature (°C)
TIT	Turbine inlet temperature (°C)
TOR	Engine torque pressure (psi)
TORC	Corrected engine torque pressure (psi)
TORC70	Corrected engine torque pressure at an EOIT of 70°C (psi)
TORS	Specification engine torque pressure (psi)
ULL	Upper limit line
WMCP	Water methanol check pressure (psi)
σ	Air density ratio at corrected pressure altitude
c (subscript)	Corrected function
$(\bar{\ })$	Average of mean of parameter value ( )
$\Delta(\ )$	Increment in parameter value ( )

1. INTRODUCTION

For a number of years, engine health monitoring has been utilised by aircraft operators to determine the condition of gas turbine engines whilst in service. The leading proponents of the techniques have been the commercial airlines whose major objective has been to reduce maintenance effort and to increase engine overhaul times without affecting aircraft safety. It is only lately that military operators have become overtly interested in in-flight engine condition monitoring; in most cases the involvement has been with automatic data acquisition systems which tend to be expensive. Reference [1],* a TTCP Technical Report, provides a summary of current military philosophies in this area.

Engine health monitoring can be separated into two distinct parts: the first, aero-thermodynamic (gas path), is concerned primarily with the performance or output of the engine whilst the second, mechanical, is related to the physical structure of the engine, that is with the condition of gears and bearings, vibrational characteristics and fatigue life of various components. It is the former aspect of engine health monitoring with which this note is concerned.

The rationale for performance monitoring is based upon the ability of a gas turbine to follow its "corrected" gas generator performance parameters under steady state operating conditions without deviation unless some internal or external force causes it to do so. If the disturbing force can be identified and corrected then the engine performance will be regained. It is the purpose of this note to describe two different techniques used to monitor turbo-prop gas turbine performance and so identify potential gas path problem areas.

The monitoring procedures were devised for two specific purposes; in the first case (Part A) it was in response to a history of problems associated with the engine torquemeter on the Rolls-Royce Dart 550-2 engine as installed in the Hawker Siddeley 748 aircraft.

In Part B a method for comparing the power levels of the T56 engine as installed in the Hercules and Orion aircraft is given. This latter procedure was developed to aid the aircraft flight engineer to monitor engine performance more consistently and hence enable engine operation and maintenance action to be carried out more effectively.

The first method involves complex data reduction procedures to account for variations in aircraft operating condition (airspeed, altitude and ambient temperature), whilst the second method eliminates these procedures but as a consequence can only be used with multi-engined aircraft. In both cases, however, manually recorded data are used to calculate trends in engine torque (shaft horsepower) and fuel flow; and thus indicate component failures or instrument malfunctions. It should be mentioned that with the simple monitoring procedures described, the isolation of a given engine fault, whether it is in the gas path components or in the instrumentation itself, can only be identified after considerable experience has been acquired. Techniques such as differential gas path analysis [2] which enable individual component faults to be determined are not discussed in this paper.

* Numbers in brackets designate references at the end of this note.

PART A

2. ROLLS-ROYCE DART 550-2

Since the introduction of the HS 748 aircraft into service with the RAAF in 1967, there have been continual problems with the torque (power) indicating system installed on the Rolls-Royce Dart 550-2 engine. The problems have ranged from a failure to give consistent readings from one take-off to the next, to occasions, during ground power checks, when a shift in the torquemeter calibration has occurred. As the torquemeter is used by the pilot as a go–no-go indicator of power available at take-off, the reliability of the system is of great concern.

2.1 Torquemeter System

The Dart torquemeter system is located within the reduction gearbox housing, Figure 1, and has the following functions:

(*a*) to ensure that each layshaft carries an equal share of the loads being transmitted through the reduction gearbox,

(*b*) to indicate the torque or power being transmitted through the reduction gears so that the level of engine power can be observed in service, and

(*c*) to supply a power signal to the water methanol unit to ensure that the correct quantity of water methanol is metered to the engine when a "wet power" (boosted) take-off is selected.

The arrangement and operation of the torquemeter system are as follows:

The layshaft teeth are helical and therefore, under load, the layshafts move forward due to the thrust loads generated in the teeth. The magnitude of the forward thrust is directly proportional to the torque passing through the gears. A common oil pressure is supplied by the torquemeter pump to pistons which oppose the forward thrusts of the layshafts. Since the thrust on the layshafts varies with the torque passing through the reduction gear so also must the opposing oil pressure vary if a balance is to be achieved. This is done by positioning a spill valve in the piston at the lower layshaft position. As power is increased, the layshafts move forward and the spill valve is gradually closed so that the oil pressure acting on the pistons increases until the forward thrusts on the layshafts are exactly balanced by the oil pressure. Similarly, as power is decreased the layshafts are pushed rearwards and the spill valve is gradually opened until again a balanced condition is achieved.

The variation of this oil pressure is used to indicate the torque output (and power level) of the engine.

2.1.1 Torquemeter Calibration

A detailed description of the calibration procedure for the Dart torquemeter system is given in [3]. Briefly it involves running the engine in a test cell at its minimum rated power (2120 SHP as indicated by the test bed statimeter), with the engine oil inlet temperature (EOIT) held constant at initially 70°C and then 100°C, and recording the respective engine torque pressures and turbine gas temperatures. The two measured values of torque pressure are known as the engine power check pressure at 70°C and 100°C, i.e. EPCP70 and EPCP100 respectively. These values are then used as the basic torquemeter–shaft horsepower conversion factors for installing the engine in the aircraft.

2.1.2 Engine Installation

The engine installation procedure is very complex and can be fraught with difficulties in the interpretation of the results; this is because two problems occur when comparing installed ground run data with test bed results. The first problem is a result of the inability to hold the EOIT at a given value during the limited period of time allowed for ground running. Figure 2 shows typical variations of torque pressure with EOIT obtained during a four-minute maximum power installation ground run. The second problem occurs when an installed engine is ground run at the same dry power levels as on the test bed, invariably the respective torque pressures are different. This difference in torque levels is known as the "installation loss". Its cause is attributed by Rolls-Royce to an interaction between the propeller and the ground or fuselage and to the propeller weight.

In an endeavour to circumvent these problems Rolls-Royce and Hawker Siddeley have evolved a complex installation acceptance procedure. Briefly it involves taking the torque pressure obtained at an EOIT of 85°C as the reference value (this is commonly known as the point K), and applying a number of acceptance limits to its value. These are detailed in Figure 3. The position of the point K and test bed determined operating limits for maximum and minimum TGTs are then used to set the pilot's minimum dry torque pressure (PMDTP). Variations in the position of the point K can be used to monitor engine power degradation from one ground power check to the next.

A complete description of the installation procedures is given in reference [4]. Suffice to say here that the conditions used to determine the initial value of PMDTP are not always repeatable and there can be occasions in service when the pilot will not obtain the required torque pressure at take-off and consequently the engine or aircraft will be rejected as being unserviceable. In an endeavour to eliminate these rejections, it was proposed that an in-flight monitoring procedure should be investigated to determine if in-service degradation or torquemeter calibration shifts could be diagnosed from flight recorded data. It was anticipated that the monitoring procedure, which would be carried out under steady operating conditions of engine performance parameters and of stabilised EOIT, would be more reliable and should provide maintenance personnel with more consistent performance data to evaluate the engine condition.

2.2 Engine Monitoring Procedure

The monitoring procedures used to investigate the performance of the Rolls-Royce Dart 550-2 engine are based upon a method proposed by Rolls-Royce [5]. In implementing the procedures of reference [5], modifications have been made to account for variations in engine oil inlet temperature which, as indicated previously, can significantly affect the torque pressure to shaft horse power conversion ratio. A synopsis of the modified monitoring procedures developed for the Rolls-Royce Dart 550-20 is given in Appendix 1. From these procedures it is apparent that it would be difficult to determine engine performance without the aid of some form of computer data analysis. This was achieved by using the ARL DEC-10 computer.

2.3 Engine Monitoring Trial

It was agreed with the operating units that a limited trial should be undertaken on two HS 748 aircraft stationed at RAAF Base East Sale prior to any general application of the monitoring procedures. In the implementation of the trial it was requested that on each flight the following parameters should be recorded, once the aircraft/engine instrumentation had stabilised, with both engines set to 14 500 RPM and a TGT of 785 C:

(*a*) pressure altitude,
(*b*) indicated outside air temperature,
(*c*) indicated airspeed,
(*d*) engine torque,
(*e*) engine fuel flow,
(*f*) engine oil inlet temperature,
(*g*) engine oil pressure,
(*h*) engine turbine gas temperature, and
(*i*) engine RPM.

These data, together with details of engine calibration, were to be forwarded to ARL for analysis and interpretation.

During the trial, which extended for approximately eight months, close contact was maintained between the RAAF operating squadron at East Sale, ARL, and RAAF HQSC under whose aegis the trial was conducted.

2.3.1 Instrumentation

In any manual monitoring procedure the consistency of the recorded data depends basically upon three criteria. These are:

(*a*) the accuracy with which any specified operating conditions are adhered to,

(*b*) the readability and interpretation of the instruments, and

(*c*) the long-term repeatability of the instruments themselves.

The first two criteria depend principally on aircrew involvement and it is therefore necessary to rely upon their expertise to provide consistent results. From discussion with pilots it was ascertained that the following gauge resolution could be maintained whilst airborne.

Parameter	*Instrument minor division*	*Resolution*
PA	—	100 ft @ 10000 ft
IOAT	2·0°C	1°C
IAS	5 knots	1 knot
Torque	20 psi	5 psi
Fuel flow	100 lb/hr	10 lb/hr
EOIT	10°C	2°C
TGT	20°C	5°C
RPM	20	5

(The layout of the HS 748 engine instrumentation is shown in Figure 4.)

With reference to the third criterion, the engine instrumentation is checked against calibrated instruments on each ground power run and at every D service (450 h).

2.4 Results of Trial

Data were obtained for two HS 748 aircraft, fitted with the following engines:

Aircraft	*Port*	*Stbd*
A10-607	18119	18122
A10-608	18115	18120

An analysis of the results was carried out at ARL in accordance with the procedures given in Appendix 1. The trend plots obtained are given in Figures 5–8 in terms of actual deviations of torque (×) and fuel flow (+) from the performance of a "standard" engine. In addition rolling averages* for both parameters were included in the graphs in an endeavour to reduce the data scatter which inevitably occurs in any manual monitoring procedure.

The abscissa of the trend plots is given in terms of Flight Number because of the difficulties associated with correctly identifying the actual engine operating hours. Superimposed on the trend plots are limit lines representing a ±10% variation in both torque and fuel flow. The limit lines were determined with respect to an average of the first five records of torque and fuel flow rather than the standard engine specification, i.e. zero deviation line.

* Rolling averages for both torque and fuel flow deviations were calculated from five consecutive readings of each function as follows:

$$\mathrm{R.A.}_N(\Delta FF) = \frac{\Delta FF_N + \Delta FF_{N-1} + \Delta FF_{N-2} + \Delta FF_{N-3} + \Delta FF_{N-4}}{5}$$

A perusal of the results given in Figures 5-8 shows that at no stage do any of the rolling average traces cross the limit lines and only on few occasions do the actual data lie outside these lines. On these latter occasions the deviations are not considered significant, as no definite trend has been established, and an analysis of the raw data shows in some cases the deviation can be attributed to gross reading errors.

2.4.1 Engine Removals or Rejections

Contrary to the normal operating experience with the Rolls-Royce Dart 550-2 turbo-prop engine, no engine removals occurred on either of the two aircraft during the monitoring period. The number of pilot initiated rejections during the period is unknown but, as indicated by the symbol ○ on Figures 5-8, the number of ground power checks carried out was small. Analysis of the ground power checks indicated that little if any engine deterioration had occurred during the period of the trial.

2.5 Conclusions

As no significant deviations in torque or fuel flow trends were indicated d[illegible]ing the period of the trial (nor were any to be expected from the analysis of the ground p[illegible] checks), the results of the trial are inconclusive. Analysis of the recorded data does sh[illegible] that consistent in-flight records can be obtained with minimal extra pilot workload. However, [illegible]omputational equipment required to analyse the data is extensive and it is considered [illegible] further engine monitoring using this technique is not warranted because it would not be c[illegible]ffective. These conclusions are complemented by the fact that during the latter period of [illegible] a separate investigation into Dart torquemeter repeatability was initiated by Rolls-Roy[illegible] conjunction with RAAF HQSC and ARL staff. This investigation resulted in modifications to the engine installation procedure and to the levels at which the pilot's PMDTP could be fixed. (The results of the Rolls-Royce investigation are given in [6].) The new installation procedures and torque limits, when incorporated in the respective maintenance and flight manuals, whilst not eliminating the torquemeter repeatability problem should provide sufficient latitude for satisfactory day-to-day operations of the aircraft without undue rejections occurring. It is considered that the most satisfactory solution to the Dart torquemeter repeatability problems would be the incorporation of a superior torque measuring system such as used in the Allison T56 (differential coaxial shaft displacement) or in the Avco Lycoming T55 (strain gauge) or the proposed electronic system being developed by Rolls-Royce for use with the Dart engine.

PART B

3. ALLISON T56

With the broad similarity of operations of the RAAF transport aircraft to their civilian counterparts, it was manifest that airline monitoring procedures should first be investigated for their suitability for use with T56 engines installed in the RAAF Hercules and Orion aircraft. It was recognised that whilst operations of the Orion aircraft during the maritime search mode were radically different from those for normal Hercules operation and civilian airline practice there would be occasions, for example during transit, when some degree of operational similarity would allow the development of common monitoring procedures. From discussions with operators of the Allison 501 engine, the civilian equivalent of the T56 engine, it was apparent that quite comprehensive monitoring procedures had been used for a number of years by aircrew to determine engine power and aircraft all-up weight at take-off, and subsequently by maintenance personnel to monitor engine condition. A synopsis of these procedures is given in Appendix 2. It was also found from overseas communications that similar techniques were being used by the USAF on the turbo-jet engines of the KC135 and by the RAF on the turbo-fan engines of the VC10 aircraft. A summary of these procedures is also given in Appendix 2.

Examination of operating methods and the EE10 and EE416 maintenance forms used by the RAAF on the Hercules and Orion aircraft indicates that for many years the flight engineer has recorded, at 30-minute intervals, all the relevant data for an engine performance monitoring analysis; a copy of a Hercules EE10 form is given in Figure 9*a*. It is understood, however, that in neither case has a systematic analysis been carried out to determine the performance of the engines. However, reference was sometimes made to the records after an engine or component failure had occurred.

3.1 Engine Monitoring Procedure

Using the information acquired fron. other operators of multi-engined aircraft, and samples of data obtained from Hercules and Orion aircraft, an investigation was undertaken to formulate a simple trend monitoring system which did not require the complex data correction methods necessary with the Dart engine. The analysis carried out and procedures evolved for the Hercules aircraft, are detailed in Appendix 3. In summary they require the flight engineer or personnel in Maintenance Control Section (MCS) to calculate for each flight, the differences in torque and fuel flow levels for each of three engines against a reference fourth engine, whilst all four engines are operating at a common turbine inlet temperature and RPM. Using this simple technique, applicable only to multi-engined aircraft, the normal requirements for data correction to account for variation in airspeed, altitude and outside air temperature from one set of readings to the next can be dispensed with.

3.2 Engine Monitoring Trial

Prior to a general implementation of the above procedures, it was proposed that a trial should be carried out on a limited number of aircraft of each type, and to enable reliable trend information to be obtained it was requested that data should be recorded on every flight. The only other requirement to be specified, as with any other monitoring procedure, was that the engine and its associated instrumentation should have attained a stabilized condition before any readings were taken.

In the original concept of the monitoring it was envisaged that the data differencing and plotting of trend graphs, for both torque and fuel flow, would be carried out by the flight engineer. The trend plots would remain in the aircraft with copies being passed to MCS after every 10–20 plotted points. In the course of discussing the trial with the operators (both aircrew and maintenance personnel), it was decided that the records taken by the flight engineer should be passed directly to MCS who would then have the responsibility for data reduction and producing engine trend plots. In addition it was agreed that data should be obtained for all aircraft. (It was believed that this procedure would detract from the essential simplicity of the original scheme and could impede its adoption by the RAAF.) Notwithstanding the previous remarks, a six-month trial on both Hercules and Orion aircraft was agreed to and was to commence in the first half of 1977. Because of a reorganisation of the maintenance procedures for the Orion aircraft, the proposed Orion–T56 trial was not proceeded with; however, it is considered that the general conclusions would be the same as those obtained for the Hercules aircraft.

3.2.1 Instrumentation

In any thermodynamic performance monitoring system the only engine faults which can be identified are those which cause changes or apparent changes to the gas path flow through the engine. That is, the faults are a direct consequence of damage or deterioration to the compressor, combustor or turbine, or can be attributed to an indicating or control system fault brought about by a malfunction in a sensor system, i.e. thermocouple degradation. In both cases the implied faults could be a result of gauge error or misreading of the basic engine parameters, hence the validity of any trend plots relies upon the long-term relative accuracy of the instruments used to monitor the engine parameters and upon the consistency of the reading taken by the flight engineer.

The layout of the engine instrumentation for the Hercules aircraft is given in Figure 10 and exemplifies the problems which can occur, during flight, in obtaining accurate readings. From discussions with aircrew, it was elicited that the following instrument resolution could be obtained.

Instrument	*Gauge range*	*Resolution*
Torque	0–25000 in lb	100 in lb
Fuel flow	0–3000–12000 lb/hr	20 lb/hr
N—% RPM	0–100%	1%
TIT	0–1200°C	5°C

In normal aircraft operation the engine speed for all four engines is invariably synchronised at 100% and the TITs set to a given value (e.g. 850°C); as a consequence the probability of errors in the N and TIT records can be almost eliminated provided care is exercised during the setting-up procedure.

Hence the only limitation on repeatability is in the accuracy of reading fuel flow and torque provided the instrument calibration is maintained. It should be emphasised that for trend monitoring the absolute accuracy of the instrument is not paramount provided that a repeatable calibration is maintained. The torque, fuel flow, speed and TIT indicating systems are [illegible] the following accuracies at their design operating point:

(*a*) torque $\pm$115 in lb,
(*b*) fuel flow $\pm$10 lb/hr,
(*c*) N $\pm 0 \cdot 5$%, and
(*d*) TIT $\pm$5°C.

In all cases the instruments are overhauled on condition, i.e. whenever a fault becomes apparent. This latter condition could be construed as imposing significant limitations on the validity of the trend plots, as drifts in calibration with time are essentially unknown. However, it is anticipated that the monitoring procedure would itself indicate gauge faults and so provide a further check on the operating system.

3.3 Results of Trial

As mentioned earlier, results have only been recorded for the T56 engine as installed in the Hercules aircraft. Records for 24 aircraft and 133 engines (including engine changes) have been obtained by the flight engineer and these data points have been meticulously plotted by personnel within the Maintenance Control Section of No. 486 squadron at Richmond.

A perusal of the records shows that during the six months of the trial no engine or instrumentation system had been rejected directly as a result of any observed deviations in either fuel flow or torque plots. A major difficulty in the trial was in obtaining up-to-date results and interpreting the trends which had been derived from the monitored data.

An analysis of the results was subsequently carried out (at ARL) by firstly examining the monthly service reports for the Hercules aircraft, to determine the numbers of engines removed and to ascertain for what cause. In those cases in which performance monitoring could have been expected to reflect the fault, the appropria sections of the trend plots were scanned to locate any significant deviations in torque or fuel flow levels. Secondly the complete sets of trend plots were examined for deviations outside the upper and lower limit levels (ULL and LLL respectively). Where major deviations had occurred, the exceedances were investigated in conjunction with the reports given on the appropriate EE500,* and an attempt was made to correlate the deviation with maintenance action carried out.

3.3.1 Trend plots

Typical trend plots obtained during the course of the monitoring trial are given in Figure 11, for Hercules aircraft A97-213. In this particular example the trends show the effect of an engine malfunction and a misreading of the engine instrumentation. In the first case, a sudden rise in torque is indicated for all three engines at position 45–46 in Figure 11*a*. This rise in torque level is sustained until position 88–89, in Figure 11*b*, when a "blue harness" was replaced on engine number 4. The torque levels then returned to approximately their original values. In the other case referred to above, a sudden fall in torque occurs at position 60; analysis of the raw data shows that this perturbation in the trend plot was linked to a reading error in the data for the number 4 engine. The superimposed dotted line indicates the true trend line.

A complete analysis of both engine removals/rejection, and faults not associated with engine removals was carried out in conjunction with the trend plots similar to those given in Figure 11. In the course of analysis it was not possible to ascertain whether the plotted data was available to MCS before an engine removal or fault was located. However, if the trend plots had been examined at an early stage and provided sufficient guide lines were available to interpret the trends then it is believed that the diagnosis of engine faults could have been improved.

3.3.2 Engine Removals or Rejections

In the course of the trial period 37 engines were removed from service. Of these removals,

12 were because they were time expired,
9 for oil leaks or low oil pressure,
2 for metal contamination,
2 for worn starter spline drive,
1 for bird strike,
1 for cracked gearbox assembly,
1 for cracked inlet housing,
10 { 5 for compressor damage,
3 for turbine damage,
1 for "blue harness" replacement, and
1 for high torque and fuel flow, and low TIT.

From the above list it was considered that only the last 10 failures could have been expected to have modified the thermodynamic performance of the engine. Detailed examination of the associated defect reports for these engines showed that five of the failures would not have been indicated by the trend monitoring whilst the remaining five should have been indicated.

* EE500: This form as shown in Figure 9*b* for the Orion aircraft is used by operators (aircrew) and maintenance personnel to record any aircraft/engine fault and its subsequent rectification.

Analysis of the trend graphs for these five engines shows that:

2 were identified on the trend plots,

2 were not identified on the trend plots, whilst

1 was removed from the aircraft before any significant monitoring had occurred (only six readings were available).

Reference to the trend plots for the two identifiable failures showed that there were specific indications of their faults occurring for a significant period before maintenance action was taken. A detailed description of the 10 defects is given in [7].

3.3.3 Faults Not Associated with Engine Removals

From a general examination of the remaining trend plots it was possible to identify only 13 deviations which were of sufficient magnitude to warrant further investigation with respect to the relevant EE500 maintenance report.

A summary of the supposed faults is given below:

(*a*) six were identified on the EE500 as being actual gas path faults,

(*b*) four were not identified on the EE500, but could be associated with incipient problems in either the thermocouple or torque indicating systems, and

(*c*) three were unidentified and are thought to be a result of reading or plotting errors.

A detailed description of the above trends/faults is given in reference [7].

3.4 Conclusions

From an analysis of both engine removals and general faults it can be concluded that the performance monitoring trial, as carried out by the Maintenance Control Section of 486 squadron, whilst providing an indication of incipient malfunctions, was not able to assist in the maintenance of the T56 engine because of the time delay in processing the recorded data. However, it must be reiterated that the procedures do indicate engine faults and if processed in realtime can add significantly to the overall knowledge on the condition of the engine.

It is recommended that the trend monitoring procedures should be carried out directly by the flight engineer subsequent to his recording the relevant parameters on the EE10/EE416 forms or modified versions thereof. The trend plots of torque and fuel flow so obtained should be retained in the aircraft from one flight to the next thus providing a continuous, up-to-date, record of engine performance which can be used by successive flight engineers or maintenance personnel to ascertain current engine performance. Further it is proposed that the above procedures should be implemented through a review of the flight engineer's duties in compiling the EE10/EE416 forms. The current requirement for meticulously recording torque/TIT/RPM/fuel flow/oil temperature and pressure every half hour is not warranted. A simple trending procedure for displaying all these parameters would undoubtedly yield more meaningful results.*

* Proposed squadron operating procedures for the Hercules aircraft, to enable the flight engineer to monitor engine performance in flight is given in Appendix 4. It is anticipated that adoption of these procedures will significantly increase the diagnosis of incipient engine faults without unduly increasing the flight engineer's or maintenance personnels' workload.

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APPENDIX 1

Engine Performance Monitoring—Rolls-Royce Dart 550-2

1. SPECIFICATION PERFORMANCE

The monitoring method proposed for use on the Rolls-Royce Dart 550-2 engines was based upon a system as supplied by Rolls-Royce but with modification to account for variations in EOIT. Basically the method proposed is to compare the actual engine performance, determined once per flight, with the specification performance of the Dart engine at the same operating conditions. Typical corrected specification data are given in Figure 12 for an engine operating at 14 500 RPM and a TGT of 785°C.

2. DATA CORRECTION

In order to compare the actual engine performance with the corrected specification data, it is necessary to determine the total temperature and total pressure at the compressor face. These parameters cannot be determined directly from the aircraft/engine instrumentation and a number of corrections have to be made to account for the effects of position, compressibility and intake recovery factors on the basic instrument reading.

2.1 Instrument Correction

Before the recorded instrument values of pressure altitude, outside air temperature and indicated air speed can be used to determine the intake total temperature and total pressure, allowances must be made for location and compressibility effects on the respective probes. These are:

(*a*) Pressure altitude

$$\text{PAC} = \text{PA} + \text{DA}$$

where DA is static and compressibility error, obtained from Figure 13*a*.

(*b*) Outside air temperature

$$\text{AOAT} = \text{IOAT} + \text{DT}$$

where DT is obtained from Figure 13*b*.

(*c*) Air speed

(i)
$$\text{EAS} = \text{IAS} + \text{DAS}$$

where DAS is combined position and compressibility factor obtained from Figure 13*c*.

(ii)
$$\text{TAS} = \text{EAS}/\sigma$$

where σ is the density ratio at the corrected pressure altitude PAC.

2.2 Compressor Inlet Parameters

The total temperature and pressure at the compressor inlet are determined from the velocity of the aircraft (i.e. TAS) using the following expressions:

(*a*) Inlet total temperature.

$$T_1 = t_0 + \left(\frac{\text{TAS}}{87\cdot 1}\right)^2 \text{K}$$

where $t_0 = \text{AOAT} + 273\cdot 2$.

(*b*) Inlet total pressure

$$P_1 = \text{RAME} \times p_o$$

where $p_o = 14{\cdot}7\left(1 - \dfrac{\text{PAC}}{145454{\cdot}54}\right)^{5{\cdot}2545}$

and RAME is a combined multiplier accounting for ram air effects and the efficiency of the Dart/HS 748 air intake; this latter value can be determined from Figure 13*d*.

2.3 Corrected Engine Parameters

The corrected values of Torque, fuel flow and RPM, which are functions of the intake total pressure and temperature, are defined as follows:

$$\text{TORC} = \frac{\text{Actual torque}}{P_1\sqrt{T_1}}$$

$$\text{FFC} = \frac{\text{Actual fuel flow}}{P_1\sqrt{T_1}}$$

$$\text{RPMC} = \frac{\text{Actual engine speed}}{\sqrt{T_1}}$$

The corrected torque value derived above is further corrected to determine its value at a reference EOIT (in this case 70°C). This further correction is obtained using the test cell derived torquemeter calibration factors EPCP70 and EPCP100, i.e.

$$\text{TORC70} = \text{TORC} - (\text{EOIT} - 70) \times \frac{(\text{EPCP100} - \text{EPCP70})}{30}$$

2.4 Specification Torque and Fuel Flow

The specification performance values of torque and fuel flow can be determined using the curves given in Figure 12, i.e.

$$\text{TORS} = f_n(\text{TAS},\ \text{N}/\sqrt{T_1})$$

$$\text{FFS} = f_n(N/\sqrt{T_1})$$

for an engine speed and turbine gas temperature of 14 500 RPM and 785°C respectively.

3. ENGINE TRENDS

Trends in engine performance (i.e. torque and fuel flow deviations from standard) are obtained by comparing the differences between the actual corrected engine performance and the specification engine performance as follows, i.e.

$$\Delta\text{TOR} = \text{TORC70} - \text{TORS},$$

$$\Delta\text{FF} = \text{FFC} - \text{FFS}.$$

Trend plots may be established by plotting sequential values of ΔTOR and ΔFF against engine hours or flight number. Engine deterioration (or instrument error) may then be determined by observing deviation of either parameter outside predetermined limit lines. The limit lines (upper and lower values) are specified with respect to the actual base-line engine performance, which is determined from the first five data points observed, and are taken as deviations of ±10% in both torque and fuel flow.

Typical trend plots are given in Figure 14 and show actual engine data together with the respective upper and lower limit lines; the results given in this example are typical of those associated with engine deterioration, as described on the figure.

APPENDIX 2

Manual Engine Monitoring—Multi-Engine Aircraft

1. CIVIL AIRCRAFT

This section gives examples of a range of manual engine monitoring procedures which are used by operators of the Allison 501 engine, the civilian equivalent of the T56 engine; details are not included of vibration or oil monitoring techniques.

1.1 Installation and/or Maximum Power Check

This check is carried out whenever an assurance of maximum power is required. It involves setting the engine at maximum power and recording the prevailing OAT, pressure altitude, torque (SHP) and fuel flow. Reference to engine specification curves (Figure 15 shows an example for maximum installed power), enables indices for percentage maximum installed torque and fuel flow to be determined. A comparison of these indices over the life of the engine may then be used to determine absolute performance deterioration.

1.2 Take-off Power Check

This check is used by a number of operators on the first four take-offs of every day to assess the individual and total power deficiencies at a specific operating point. The power deficiency is then used to calculate the aircraft operating weights and limits on subsequent flights. Briefly the following procedure is carried out:

(*a*) On the engine being checked, the TIT is set to a predetermined value and the torque achieved at 80 knots noted. Using power charts, provided by the engine manufacturer, the specified power at 80 knots for the prevailing IOAT and PA is calculated and compared with that achieved. This procedure is repeated on the three subsequent take-offs for each of the remaining engines.

(*b*) Using the difference between the achieved and calculated power levels, the following criteria are implemented:

(i) If an individual power deficiency is greater than 400 SHP or the total power deficiency is greater than 675 SHP, then maintenance action will be required at the next stopover.

(ii) If neither of the preceding conditions apply then an IOAT correction is calculated on the following basis, i.e. $\Delta IOAT \equiv +1^\circ C$ for every 75 SHP power deficiency. (N.B.: If the total power output is greater than four times the standard power (for one engine) then the temperature correction is set to zero.)

(iii) The IOAT correction is then added to the prevailing value of IOAT on each subsequent flight and used to determine the permissible aircraft operating weight for take-off. By this procedure, the condition of all four engines is continually assessed and account taken of any deterioration in power levels.

The procedure detailed in (*a*) and (*b*) are recommenced on each day with the IOAT correction derived from the previous day being used until at least four flights have been carried out, and a new value of the IOAT correction calculated.

1.3 Cruise Power Check

This check, carried out on the first flight of each day, involves setting the engines to a predetermined cruise power, TIT, and then recording torque, FF, IAS, IOAT and PA. Then with reference to standard cruise performance graphs, see Figure 16 (for SHP only), the percentage standard power and fuel flow for the engines are determined and the following procedures carried out:

(*a*) If the percentage power or fuel flow is greater than 103% or 101% respectively, then the cruise operating TIT is reduced to a temperature so that 103% power or 101% fuel flow is not exceeded for the remaining flights for that day. (N.B.: Climb power TITs are also reduced in the same proportion as the values determined in the cruise check.)

(*b*) Record the results of the cruise power check on the monthly record sheet for subsequent analysis by maintenance personnel to determine engine performance degradation and particularly thermocouple deterioration.* This latter condition is normally indicated by an increase in engine power and fuel flow.

2. MILITARY AIRCRAFT

No specific details are available for engine performance monitoring procedures being carried out by military operators of the Allison T56† engine. There are, however, a number of simple monitoring procedures being used by the military on other multi-engined aircraft; two examples are given.

2.1 Shepherdson Techniques—VC10 Aircraft

This cruise monitoring power check was developed specifically for turbo-jet/fan aircraft with more than two engines. The procedures used are independent of the prevailing ambient conditions and utilize EPR as a datum parameter. Briefly, it involves throttling all engines back to a common EPR and after a stabilization period recording the respective values of engine speeds N_1, N_2, FF, and TGT. Analysis of this data is carried out in-flight by the flight engineer using an electronic hand calculator in the following manner:

(*a*) Determine an average over all of the engines for each of the parameters recorded, i.e.

$$\bar{N}_1 = (N_{1(1)} + N_{1(2)} + \ldots N_{1(n)})/n$$

$$\bar{N}_2 = (N_{2(1)} + N_{2(2)} + \ldots N_{2(n)})/n, \text{ etc.}$$

(*b*) Calculate for each engine, differences between the actual parameter value and the average value, i.e.

$$\Delta N_{1(1)} = N_{1(1)} - \bar{N}_1$$

$$\Delta N_{1(2)} = N_{1(2)} - \bar{N}_1, \text{ etc.}$$

(*c*) Plot the parameter differences, calculated in (*b*) above, to produce trend curves for each engine. Deviations in these differences, with time, from a baseline established from initial readings are used by the flight engineer or maintenance personnel to assess engine degradation.

* Thermocouple deterioration (i.e. TIT indication) is a major problem in Allison 501/T56 engines as its effects can seriously impair the integrity of the turbine assembly.

† Since the completion of this note a monitoring procedure for use on the Allison T56 engine as used by the RNZAF has been published in [8]. The methods used are similar to those given in Appendix 3 but are more complex in that differences of the quotients FF/TOR and TIT/TOR for three engines referenced against the fourth are used to monitor engine degradation. Analysis of both procedures (ARL and RNZAF) has shown that there is little difference in the diagnostic capability of the two methods.

2.2 KC135 Aircraft

The engine monitoring procedure used on this aircraft is not as simple as the direct comparative methods used on the VC10 aircraft and the proposed system for the Hercules and Orion aircraft; however, it does reduce some of the complexity associated wtih the data correction given in Part A.

Briefly the procedure involves recording the parameters PA, M, IOAT, N_1, N_2, EGT and FF once per flight with all engines set to a specified EPR. The recorded data is then modified, by use of charts and tables, to refer the performance of the engines to a selected M and PA, in this case $M = 0 \cdot 5$ and PA = 30,000 ft.

Service evaluation by the USAF of this procedure has indicated savings of up to $6·2 million on the maintenance of the KC135 fleet; currently trials are being carried out on the effectiveness of the procedures on the USAF Boeing B52 and General Dynamics FBIIIA aircraft [9].

APPENDIX 3

Engine Performance Monitoring—Allison T56

1. SPECIFICATION PERFORMANCE

A basic engine performance monitoring procedure for the Allison T56 engine can be defined by comparing the actual engine data obtained from the flight engineers' EE10 and E416 record sheets with the manufacturers' engine specification data, Figure 17. The main problem with this system, as with the Dart performance monitoring detailed in Appendix 1, is that complex data correction methods have to be applied to account for the effects of PA, IAS, IOAT and TIT. Notwithstanding the above remarks, the percentage variation of actual engine performance, using torque and fuel flow values taken from the flight engineer's record sheets, was calculated with respect to the engine specification performance. Figure 18 shows typical results, with upper and lower limit lines, representing $\pm 5\%$ change in the mean engine performance, superimposed on the resultant trend plots.

Examination of the trend lines for percentage variation in torque indicates that there is a significant relationship between each of the four plots. The interdependence can be attributed to the use of the common correction parameters, PA, IOAT, IAS and TIT; a misreading in one of the parameters will be seen on each of the engine trend plots.

2. COMPARATIVE — CORRECTED ENGINE PERFORMANCE

The deviations resulting from errors or misreading in any of the correction parameters can be eliminated by comparing the corrected engine performance for three engines against a reference fourth engine. Figure 19 shows delta torque plots for the results given in Figure 18 and illustrates how the interdependency has been eliminated. The trend plot for the fourth, reference engine, is now by definition a horizontal straight line; performance variations in the fourth engine are now inferred by simultaneous and equal changes in the trend plots of the other three engines. It is to be noted that this method of differential analysis of engine performance whilst reducing the major variations due to errors in the correction parameters, still involves complex data correction procedure to account for variations in ambient conditions, and as a consequence is not a suitable method for a manual, in-flight monitoring procedure.

3. COMPARATIVE — ACTUAL ENGINE PERFORMANCE

In normal operation of a Hercules or Orion aircraft, the rotor speeds of the T56 engines are synchronised to 100% and the power output varied by setting specific turbine inlet temperatures. Invariably the TITs are held at a common value and differences in power output manifest between engines at one TIT setting will be consistent at another power level or TIT. Hence if a differential analysis of engine performance is carried out using actual power levels attained, the results should be similar to an analysis using corrected data. Figure 20 shows results for such an analysis using the basic engine data from which Figures 18 and 19 were derived. A comparison of all three sets of trend plots shows that essentially there is little difference in trends and their relationship with the upper and lower limit lines, thus indicating that for a multi-engined aircraft actual, rather than corrected, performance results can be used directly to monitor engine performance.

Application of differential monitoring procedures using comparative data does present some difficulties in that a reassessment of all mean performance levels and the respective limit lines must be initiated if the reference (fourth) engine is changed. It is considered that this should present little difficulty either in the field or at base maintenance level. The operating instructions specified for a trial of this simplified monitoring method, as applied to the Hercules aircraft, are given in reference [7]; similar instructions have also been developed for the Orion aircraft.

1. INTRODUCTION. The object of manual engine performance monitoring is to diagnose, through observation of engine/aircraft instrumentation, the condition of the engine whilst in service and to enable changes in performance to be identified before their effects become detrimental to the operation of the engine or aircraft. As a consequence of this, maintenance effort can be reduced and overhaul times extended without affecting aircraft reliability or safety. The rationale for performance monitoring is based upon the ability of a gas turbine to follow its "corrected" performance parameters, at steady state operating conditions without deviation unless some external or internal force causes it to do so. Normally in any performance monitoring procedure it is necessary to "correct" the observed data for variations in ambient conditions, however, in the case of a multi-engine aircraft (such as a Hercules) a much more simple method has been evolved which uses one engine as a reference against which the remaining engines can be compared. In its basic form it involves the flight engineer recording once per flight, during stabilized operating conditions, the respective fuel flow and torque levels for each engine so that relative changes in engine performance can be determined: detailed operating instructions for the Allison T56 engine in the C130 Hercules aircraft are given in the following section.

2. OPERATING PROCEDURES. Once per flight, during stabilized flight conditions, i.e. when the **aircraft's airspeed has stabilized**, with normal bleed air and auxiliaries operating and with all four engines operating at 100% N_1 (13820 rpm) and with the Turbine Inlet Temperatures (TIT) set to a common value, record the observed torque and fuel flow for all 4 engines.
N.B. For reliable trends to be obtained from performance monitoring it is desirable to record data on each flight, however, on short training flights it may not be possible for sufficiently stabilized engine operating conditions to be obtained which would allow accurate data to be recorded, on these flights the trend plots should be annotated as described in section 3b.

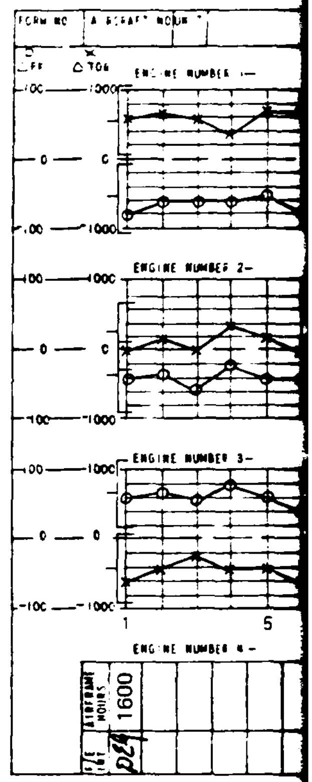
3. TREND PLOTTING.

a. Taking the values of torque and fuel flow noted in section 2 calculate for engines 1-3, using engine number 4 as a reference, the following increments (decrements) in torque and fuel flow.
Δ 14 Torque = Torque No. 1 – Torque No. 4
Δ 24 Torque = Torque No. 2 – Torque No. 4
Δ 34 Torque = Torque No. 3 – Torque No. 4
Δ 14 F.F. = Fuel Flow No. 1 – Fuel Flow No. 4
Δ 24 F.F. = Fuel Flow No. 2 – Fuel Flow No. 4
Δ 34 F.F. = Fuel Flow No. 3 – Fuel Flow No. 4

b. Plot the increments (decrements) in torque and fuel flow levels, determined above, once per flight in the manner indicated in FIG. 1 (For ease of identification torque deviations should be plotted in red with a X and fuel flow deviations are in blue with a ·). After plotting each point the F.E. is to insert the current airframe hours and initial the records at relevant position given in FIG. 1; on flights where no records were obtained the trend lines are to be marked as shown in FIG. 1 (at position 15) with the symbols NIFM (No Inflight Monitoring) and the airframe hours slot also annotated with the symbols NIFM and initialled by the Flight Engineer.

c. Using the first 10 calculated plotted points mean values of Δ torque and Δ fuel flow are to be calculated for each engine; these mean values are then used as a basis for determining limit exceedance lines representing deviations of ± 500 in lb of torque and ± 50 lb/hr of fuel flow. The limit lines are then to be superimposed on the respective engine trend plot as indicated in FIG. 1.

d. If during trend plotting of a particular engine or engines a consistent deviation in Δ torque and/or Δ fuel flow outside the limit lines occurs (i.e. 3-5 consecutive points) then action should be initiated consistent with the following criteria,
1. If only one engine deviates outside the specified limit lines then the performance of that engine should be suspect.
2. If all three engines consistently deviate outside the limit lines then the performance of the fourth engine should be investigated.
3. In either case, above, the deviation in trends should be reported to the OIC of the Flight Line. (An example of significant deviation in fuel flow is given in FIG. 1 for engine number 1 between points 19 and 24).



e. Once performance
anytime engines 1,
then new mean va
be calculated for t
associated instrum
and fuel flow devi
ing recommenced.

f. On completion of
should be transfer
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storage and future

4. CAUTION. Whilst in
should be exhibited in ov
parameter changes, (see fo
3). If there is any doubt co
the calculations should be
monitoring procedure, the
before readings are taken,
required for all engines th

5. INTERPRETATIONS
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a. Low Torque – Hi
b. Low Torque – Lo
damage,
c. High Torque – Hi

N.B. It should be empha
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investigation.

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jine whilst in
s become
maintenance
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gas turbine to
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light engineer
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30 Hercules

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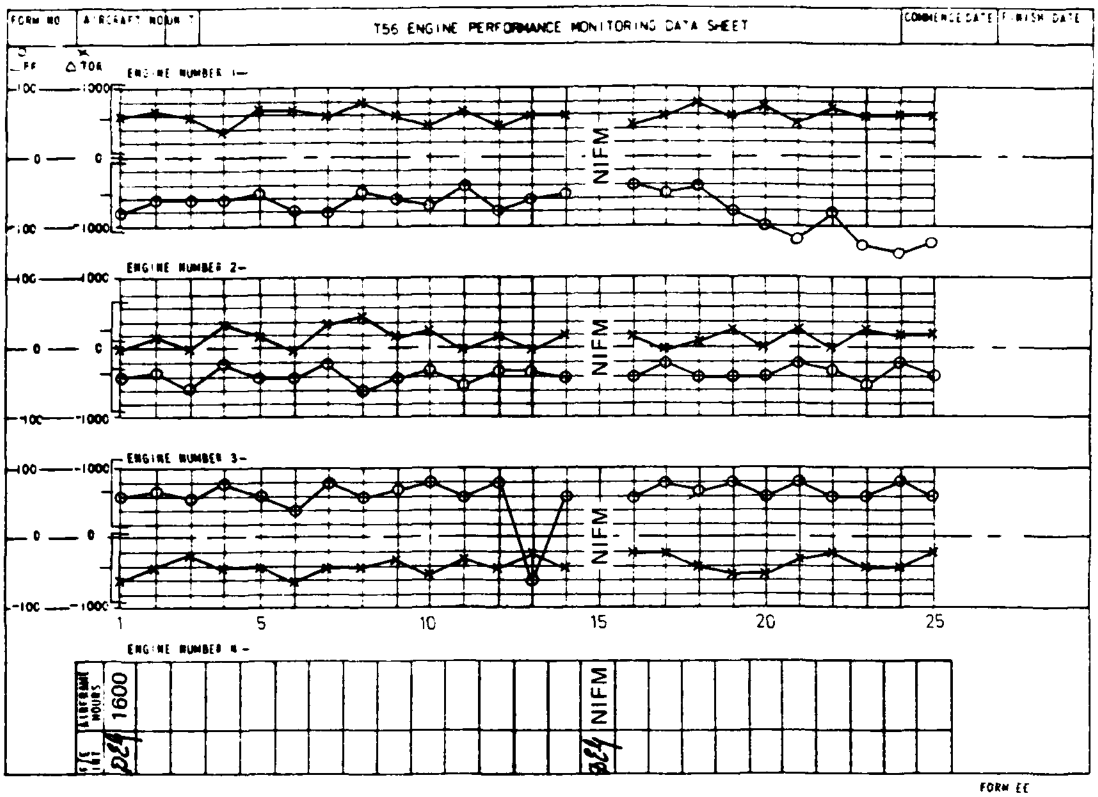

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in FIG. 1

e. Once performance trend monitoring plots have commenced for a given aircraft, then anytime engines 1, 2, or 3 are changed, or instruments associated with them modified, then new mean values and limit lines for the torque and fuel flow deviations should be calculated for that engine. If, however, the Number 4 engine is changed or its associated instrumentation modified then new mean values and limit lines for torque and fuel flow deviations must be calculated **for all the engines** and the trend monitoring recommenced.

f. On completion of a trend graph sheet, the exceedance limit lines for each engine should be transferred to a new graph sheet and the trending continued. The completed trend monitoring graph should be passed to the OIC of the Flight Line for storage and future reference.

4. CAUTION. Whilst investigating any deviation of the trend monitoring lines caution should be exhibited in over reacting to and drawing conclusions from single, abrupt, parameter changes, (see for instance point number 13 on the fuel flow line for engine number 3). If there is any doubt concerning the validity of a trend point, then the data recording and the calculations should be repeated: it cannot be stressed often enough that in any manual monitoring procedure, the engine/aircraft instrumentation should be allowed to stabilize before readings are taken, and if specified operating conditions such as fixed TIT and N1 are required for all engines then these should be strictly adhered to.

5. INTERPRETATIONS OF TREND LINES. In perusing the trend plots for a given engine the following general guide lines may be applied to investigate a suspected engine malfunction:

a. Low Torque – High Fuel Flow trends; inspect for turbine or combustor damage,
b. Low Torque – Low Fuel Flow trends; inspect for compressor contamination or damage,
c. High Torque – High Fuel Flow trends; check for thermocouple deterioration.

N.B. It should be emphasised that the above guidelines are only general, and precise causes of engine faults can only be determined by the appropriate maintenance inspection and investigation.

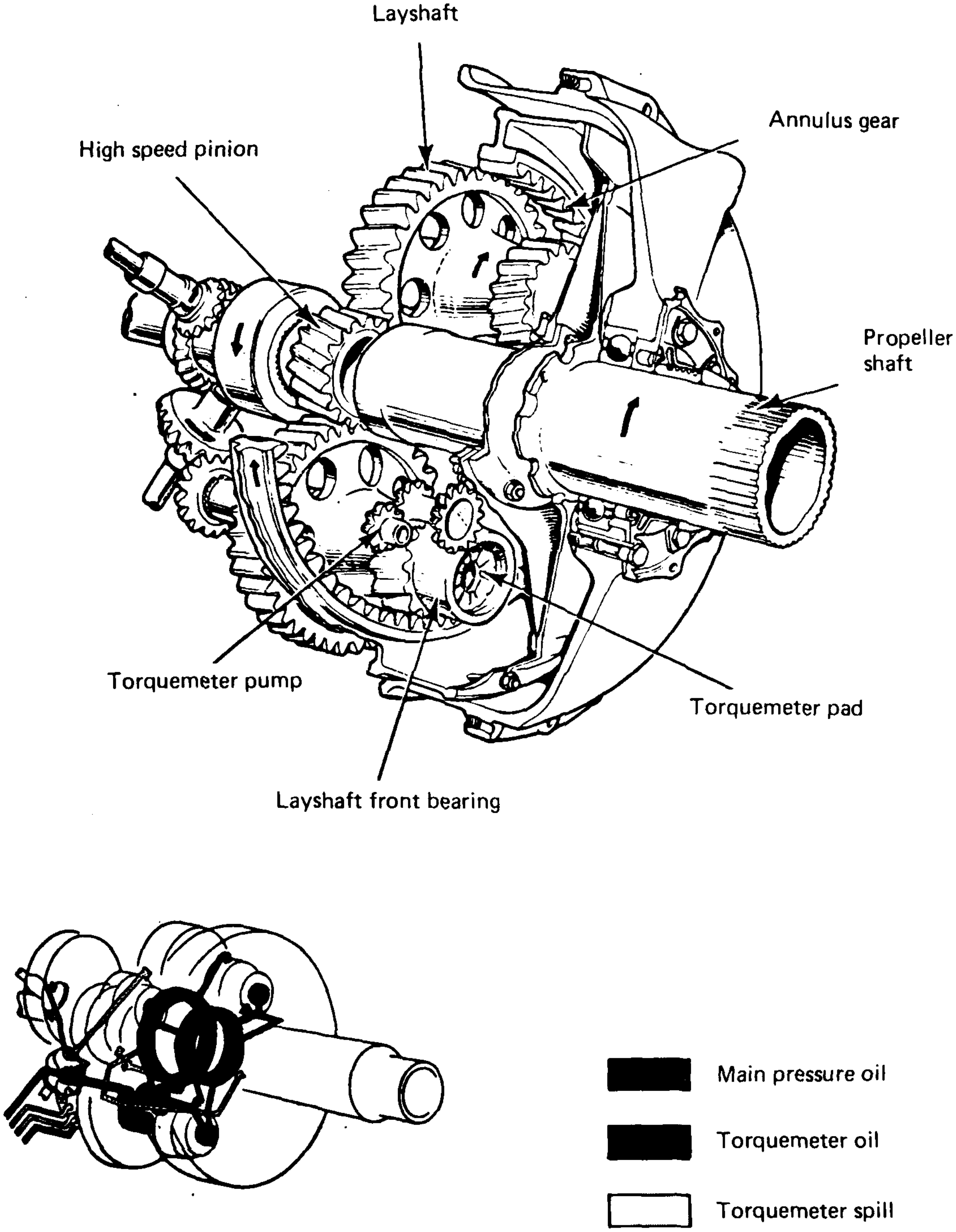


FIG 1 DART REDUCTION GEARBOX

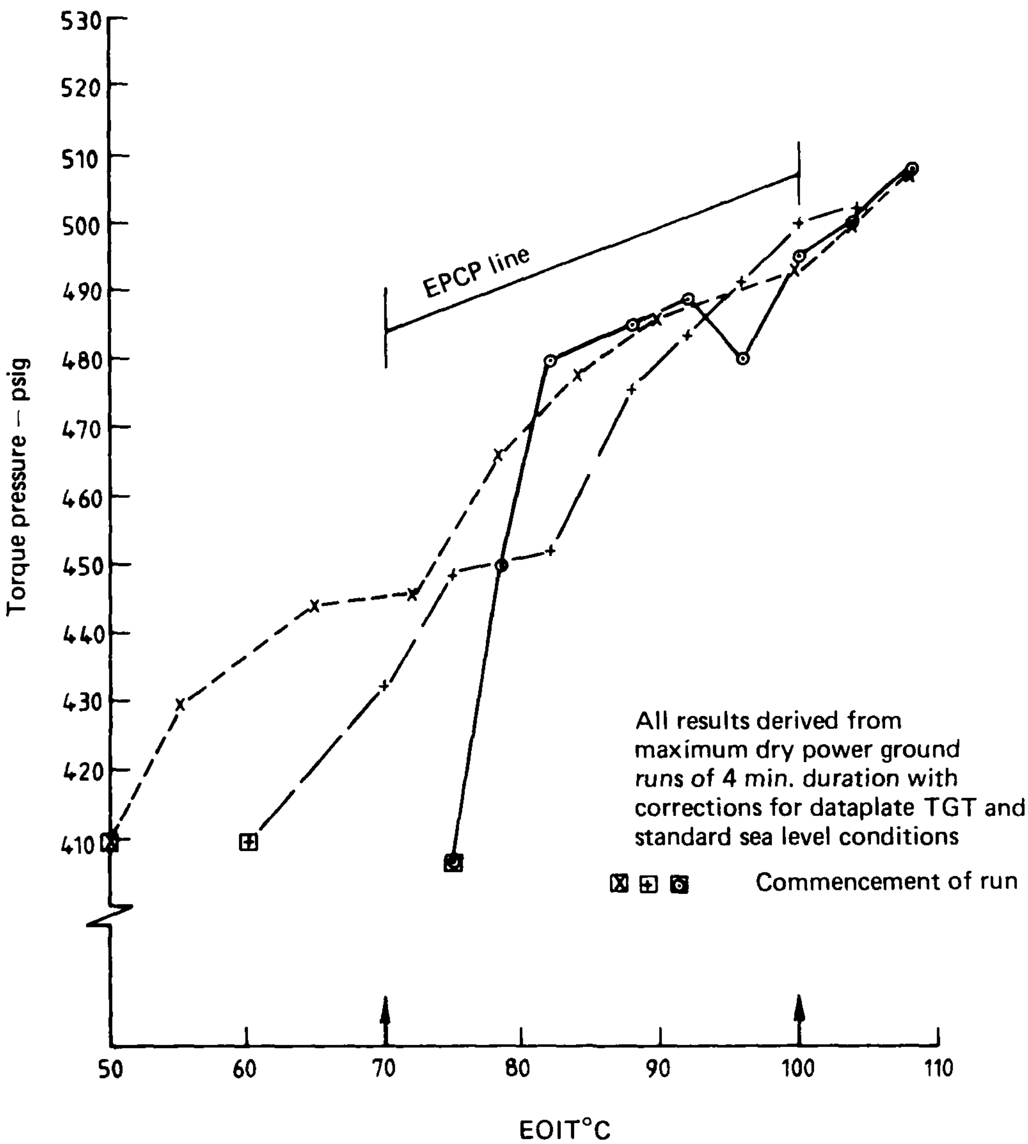


FIG 2 TORQUE PRESSURE v EOIT FOR VARYING STARTING VALUES OF EOIT

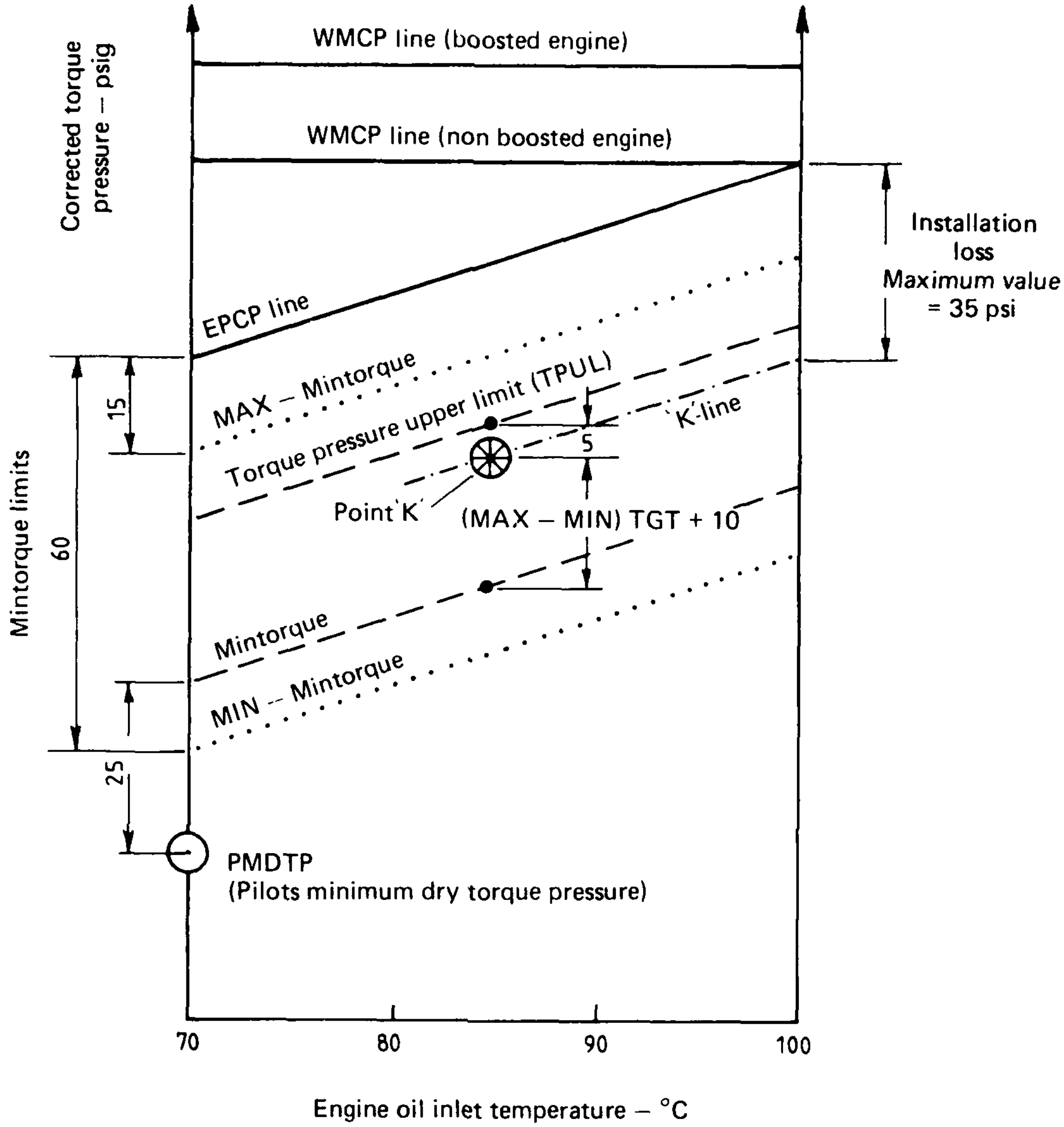


FIG 3 INSTALLATION – TORQUE PRESSURE CORRECTION CHART (INSTALLATION LIMITS)

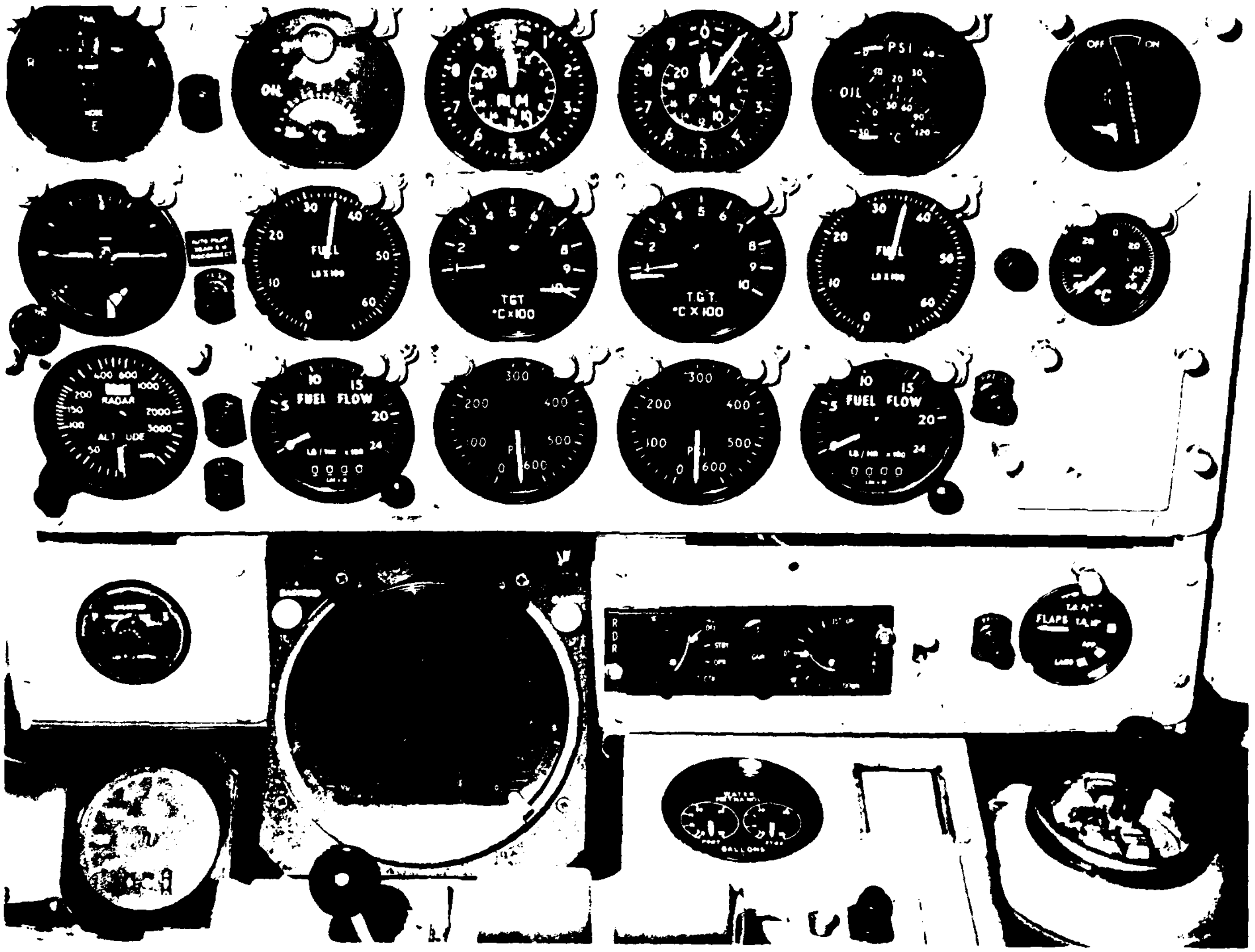


FIG HS 748 AIRCRAFT DART ENGINE INSTRUMENTATION

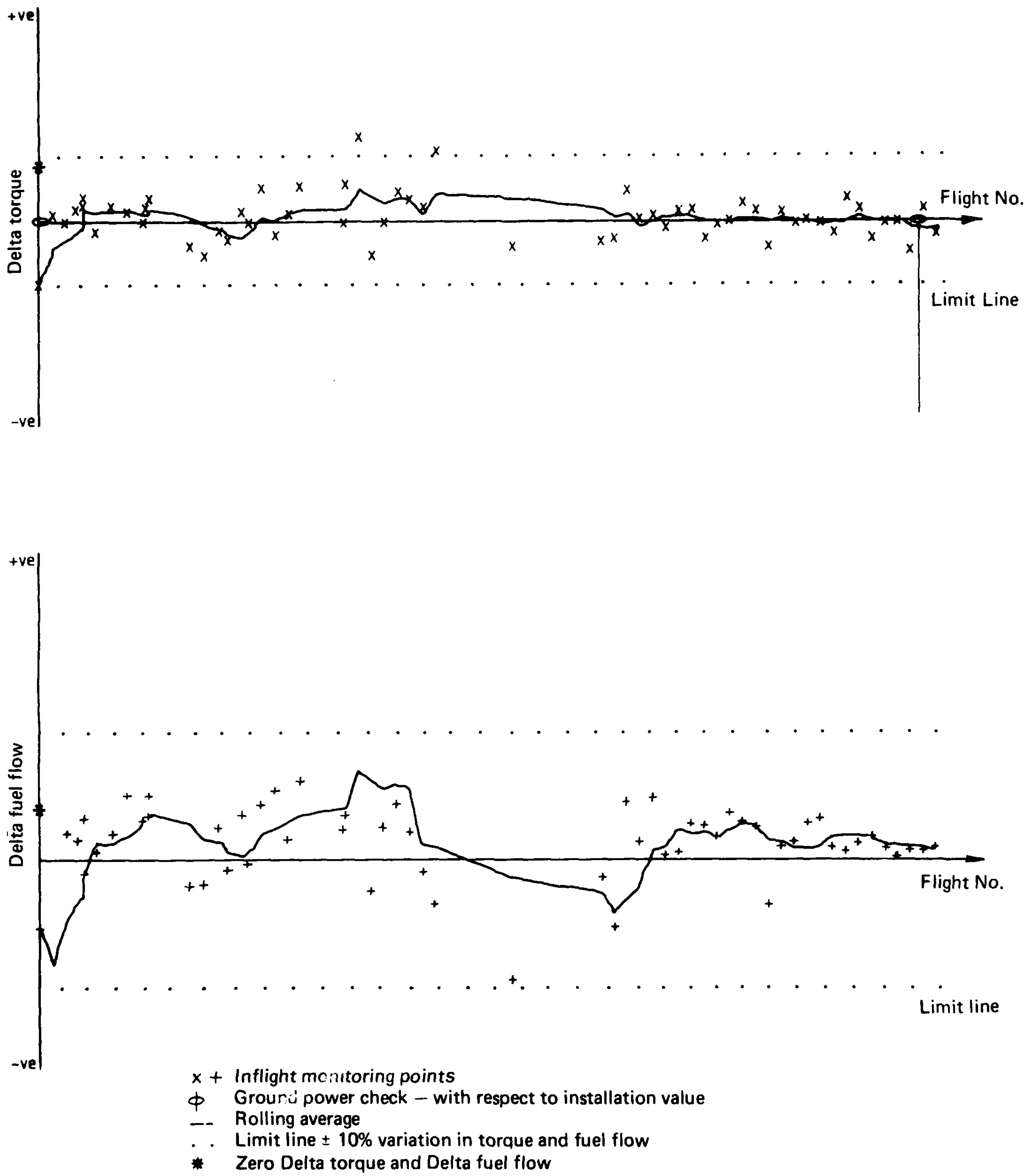


FIG 5 TREND PLOTS – TORQUE AND FUEL FLOW
A/C 607 ENGINE NO. 18122

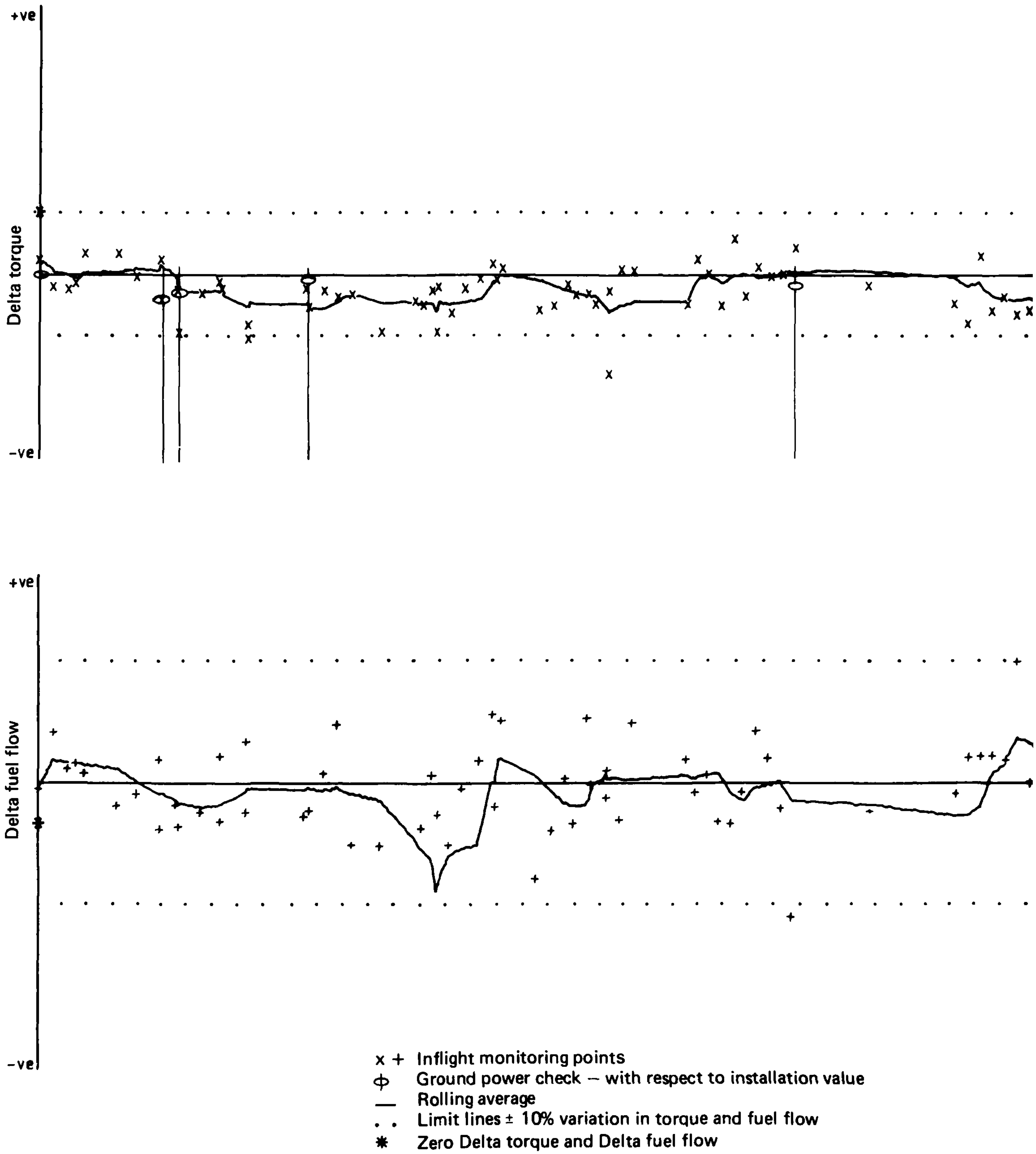
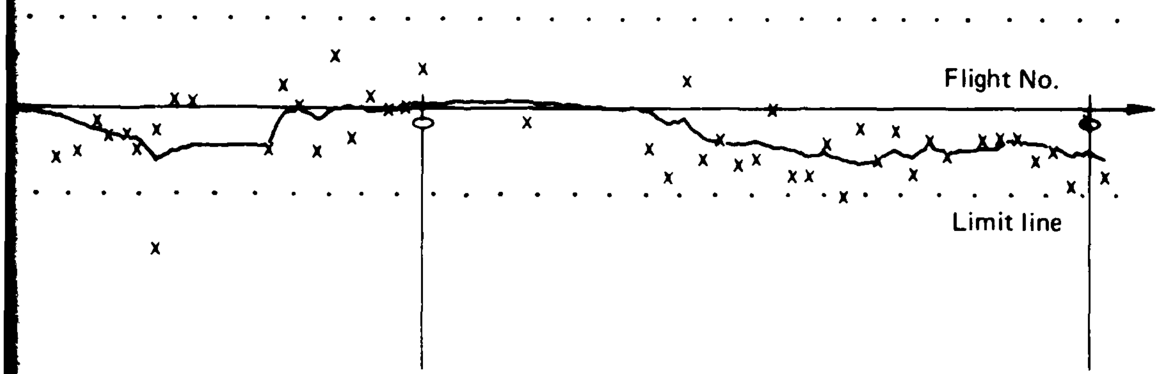
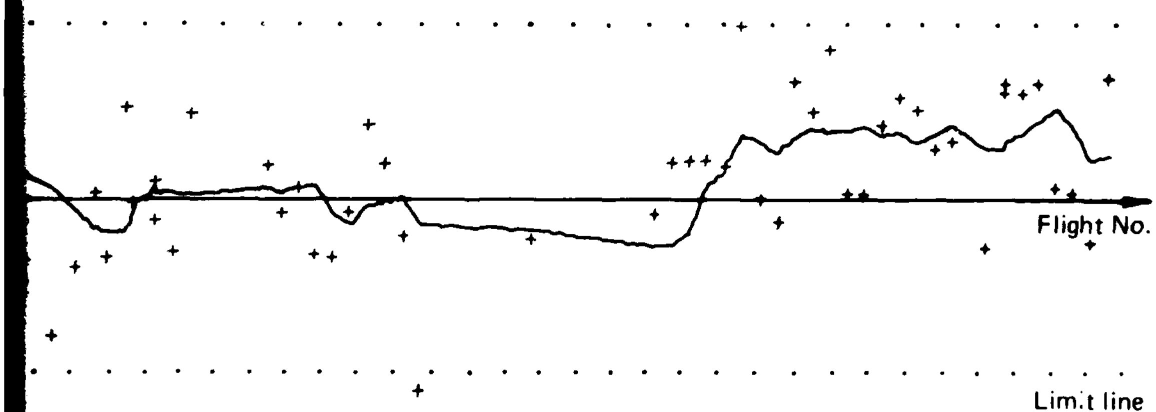


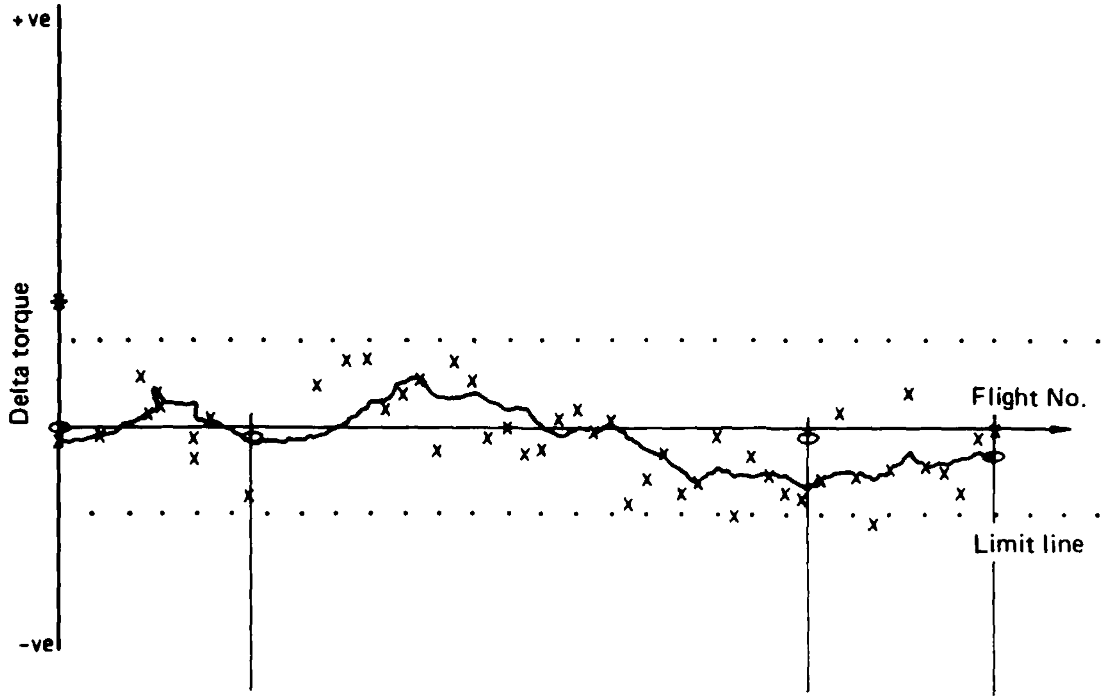
FIG 6 TREND PLOTS – TORQUE AND FUEL FLOW
A/C 607 ENGINE NO. 18119

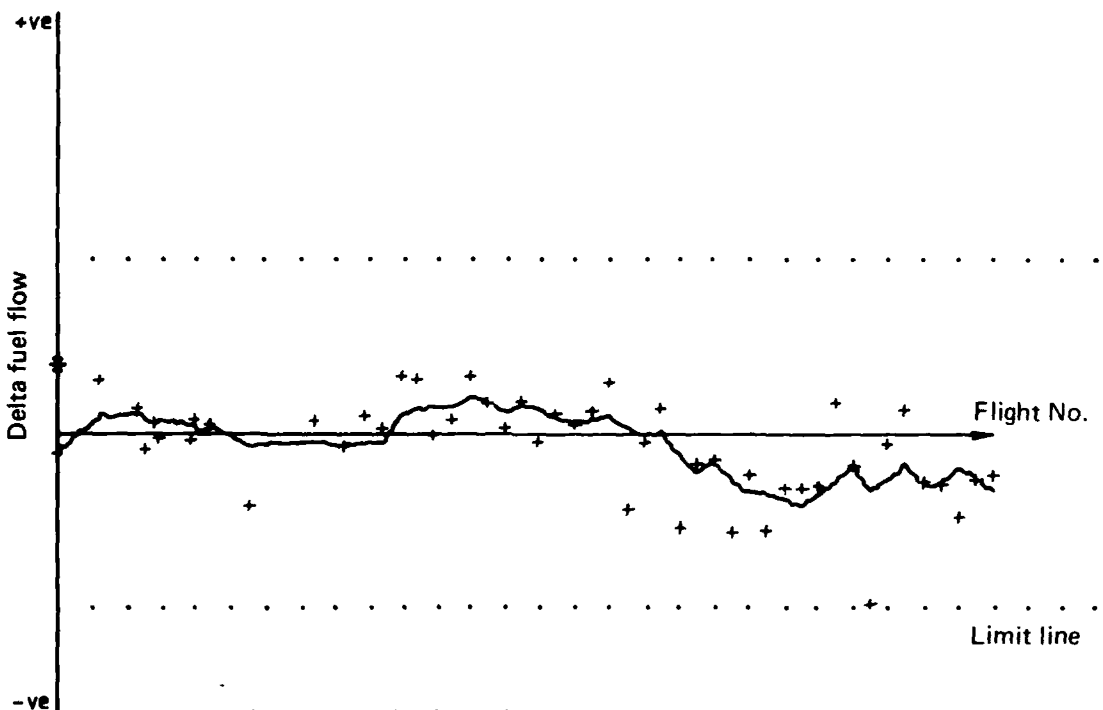




toring points
r check – with respect to installation value
e
10% variation in torque and fuel flow
rque and Delta fuel flow

D PLOTS – TORQUE AND FUEL FLOW
A/C 607 ENGINE NO. 18119





x + Inflight monitoring points

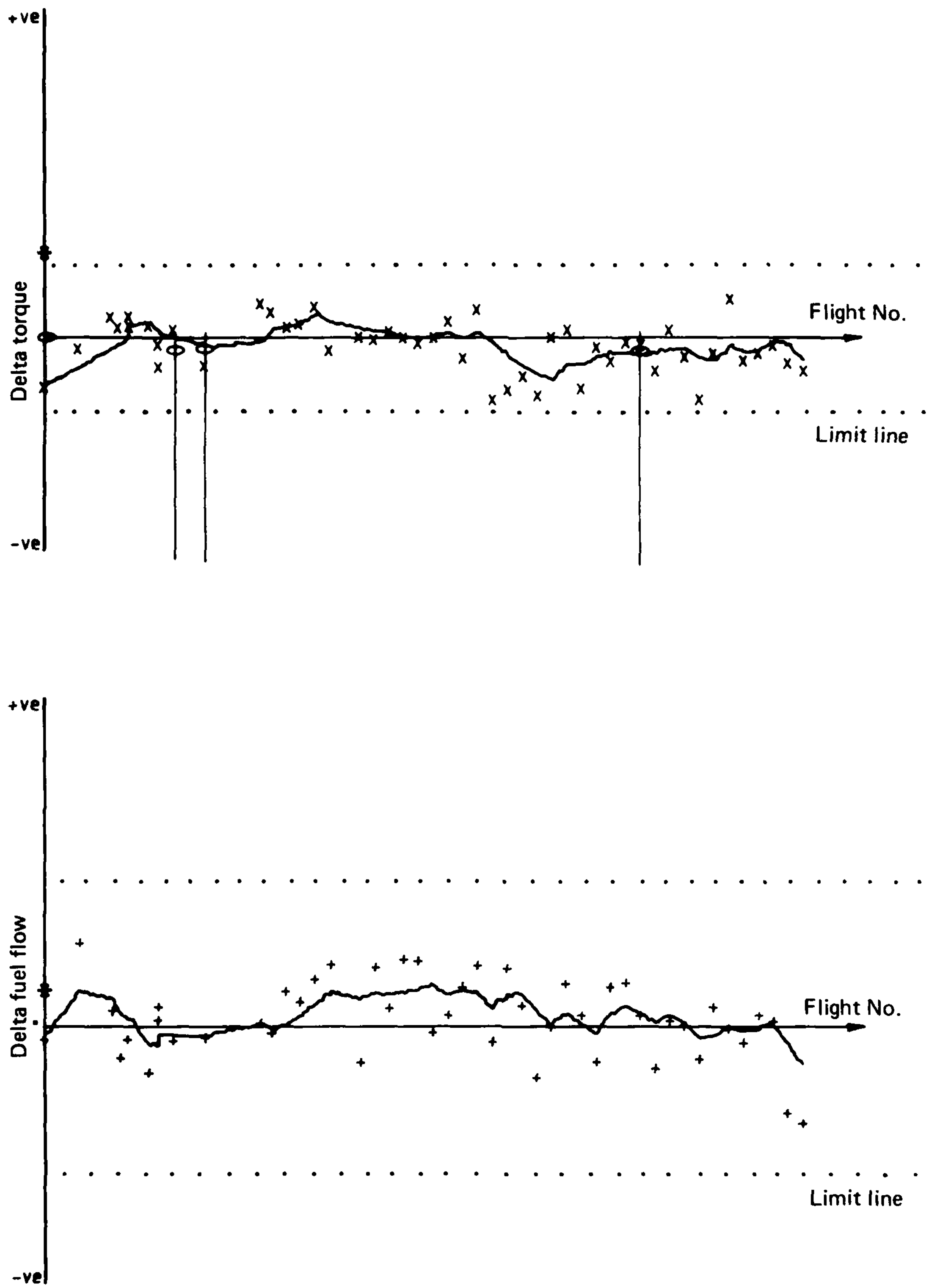
⦶ Ground power check – with respect to installation value

— Rolling average

. . Limit line ± 10% variation in torque and fuel flow

✱ Zero Delta torque and Delta fuel flow

FIG 7 TREND PLOTS – TORQUE AND FUEL FLOW
A/C 608 ENGINE NO. 18115



x + Inflight monitoring points
ф Ground power check – with respect to installation value
— Rolling average
. . Limit line ± 10% variation in torque and fuel flow
✱ Zero Delta torque and Delta fuel flow

FIG 8 TREND PLOTS – TORQUE AND FUEL FLOW
A/C 608 ENGINE NO. 18120

Royal Australian Air Force

EE10 – FLIGHT ENGINEER'S LOG, C130

Mar 71 Stock No. 7530-04-1614

Aircraft No A97-	Trip	Date	Engineer	Captain

Condition / Time	Coat / IAS	Fuel Remaining by Fuel Flow / AUW	Pressure Altitude / Cabin Altitude	Eng	TDR	RPM	TIT	F/F LB/HR	Total Fuel Flow	Oil Temp	Oil Pressure Engine	Oil Pressure Gear	Oil Qty	Fuel Remaining by Gauges Extern	Aux	Main	Total	REMARKS
				1														
				2										L	L			
				3														
				4										R	R			
				1														
				2										L	L			
				3														
				4										R	R			
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				1														
				2										L	L			
				3														
				4										R	R			

FIG 9(a) EE 10 – FLIGHT ENGINEERS LOG C130 HERCULES

Form Code	Form Number	Aircraft No	Date	Unit	Flight Duration	Engine Duration			CAPTAIN'S RELEASE		Department of Defence (Air)
ACOP	Nº 006353	A9–				No 1	No 4		Signature	DTG	MAINTENANCE FORM ORION P3
									1		
									2		
									3		EE500-A9

Engine Starts				APU Duration	Landings	Weap Sys Comp Duration	Retro Rounds Ejected	Exhaust Fan Hr Meter	Searchlight Struck	Acft Disarmed
No 1	No 2	No 3	No 4						YES/NO	Inits DTG

Placed Unserviceable By	Details of Unserviceability	Trade	Corrective Action and/or Reason for Item Change	Failure Report No	Certified 1 Tradesman 2 NCO & DTG
1					1
					2
2					1
					2
3					1
					2
4					1
					2
5					1
					2
6					1
					2
7					1
					2
8					1
					2

Unsvc Ser No	Item Name	Position	Serial No OFF	Serial No ON	Unsvc Ser No	Item Name	Position	Serial No OFF	Serial No ON	MCS Action	
										Times	
										CHRS	
										Mods. TI's	
										File	

FUEL				OIL					OXYGEN SYSTEM	TYRE PRESSURE	
Added	Total	+–	Total	PO	PI	SI	SO	APU	Total	Nose	Main
				Added	Added	Added	Added	Added			
Inits											
DTG											

ARMAMENT STORES						
Sonobuoys	Qty	Type	Qty	Type	Qty	Certified Listed Stores Fitted
SSQ		MM		Photoflash		
SSQ		SUS				
SSQ		FF				Inits
SSQ		Retro				DTG
SSQ						

Servicing Data	Prog Acft Hours				'A' Servicing Due		'B' Servicing Due		'C' Servicing Due								
Servicing	PO	PI	SI	SO	APU	Cocks	Afm	Inst	Elec	Arm	Rad	SEW	Gn			Tools	NCO	DTG
AF																	
NCOIC Trade																	

MAINTENANCE RELEASE		
All Maintenance Completed EXCEPT		Releasing Base
Signature	Rank	DTG

CAPTAIN'S ACCEPTANCE	
Signature	DTC
1	
2	
3	

FIG 9(b) EE 500 FORM – ORION AIRCRAFT

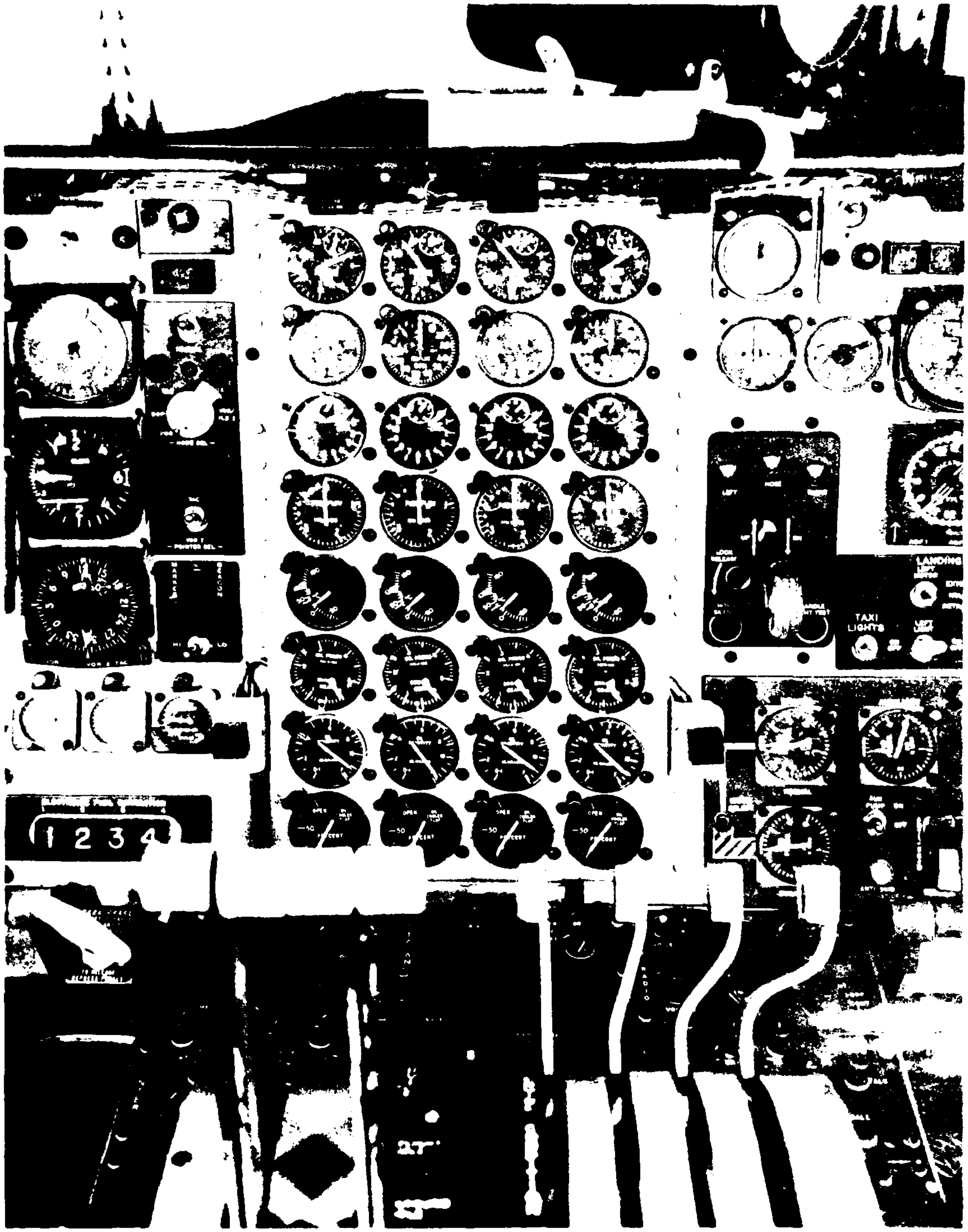

FIG 10 HERCULES AIRCRAFT T56 ENGINE INSTRUMENTATION

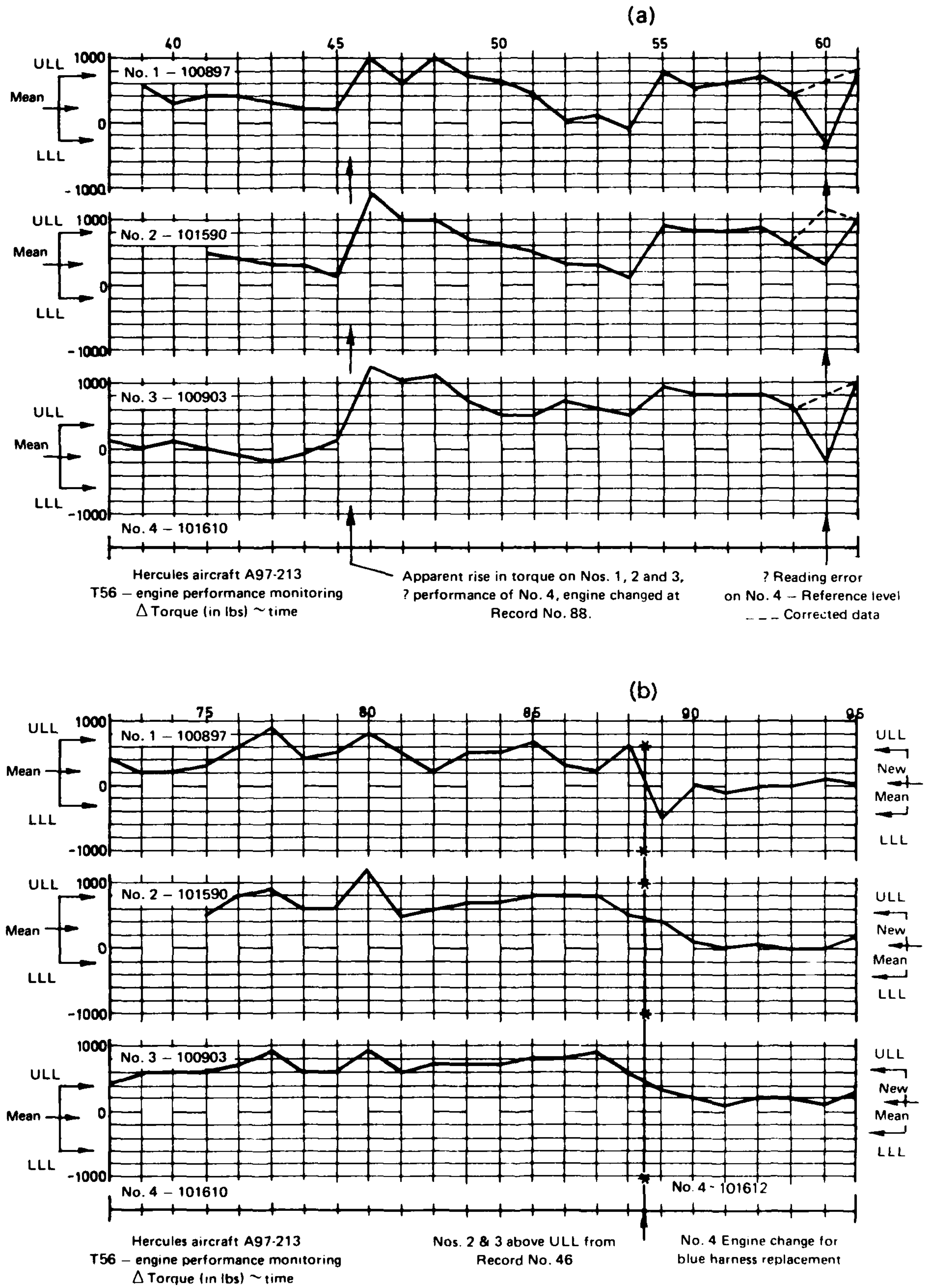

FIG 11 TREND PLOTS HERCULES AIRCRAFT A97-213

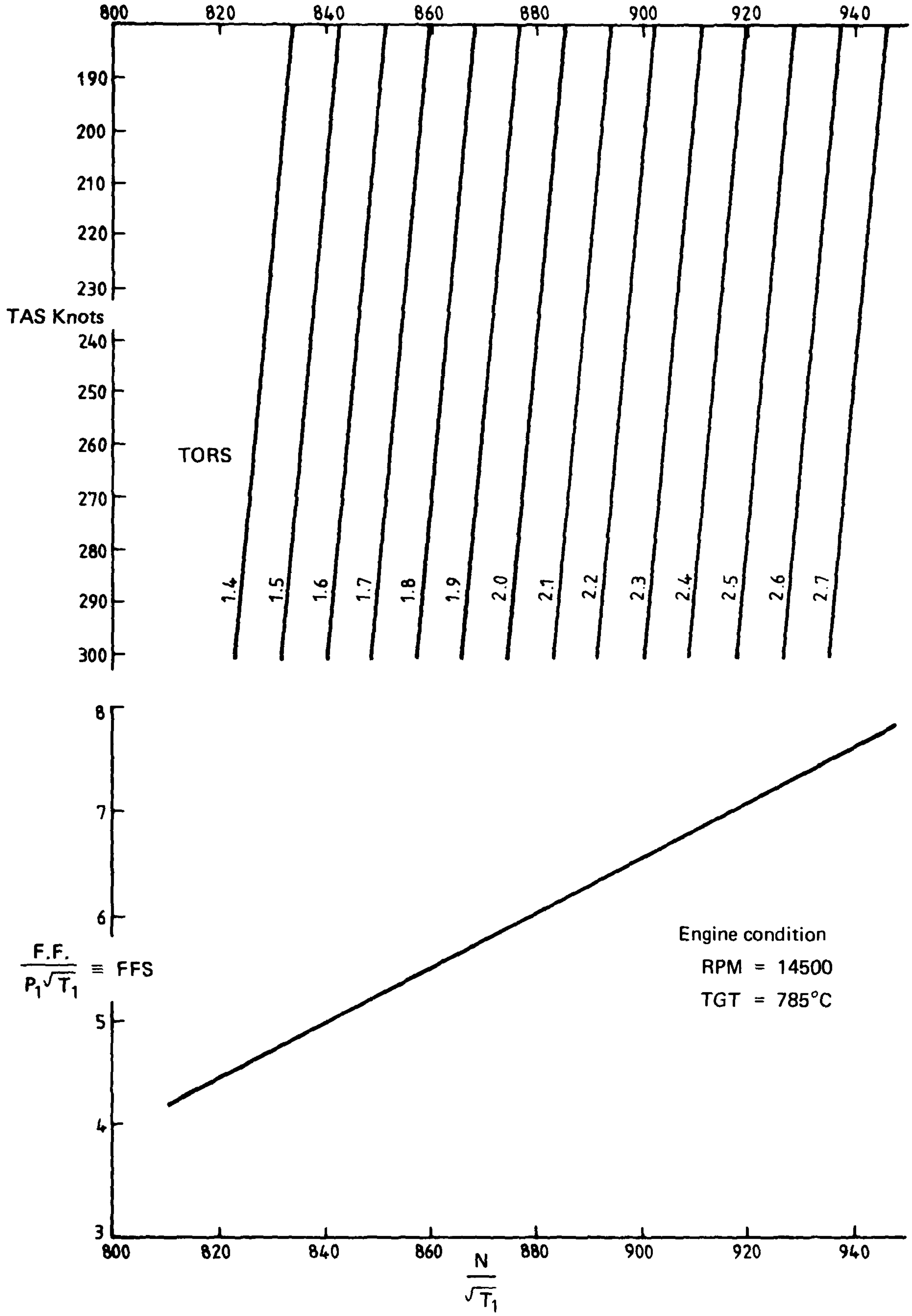

FIG 12 DART 550-2 SPECIFICATION ENGINE PERFORMANCE

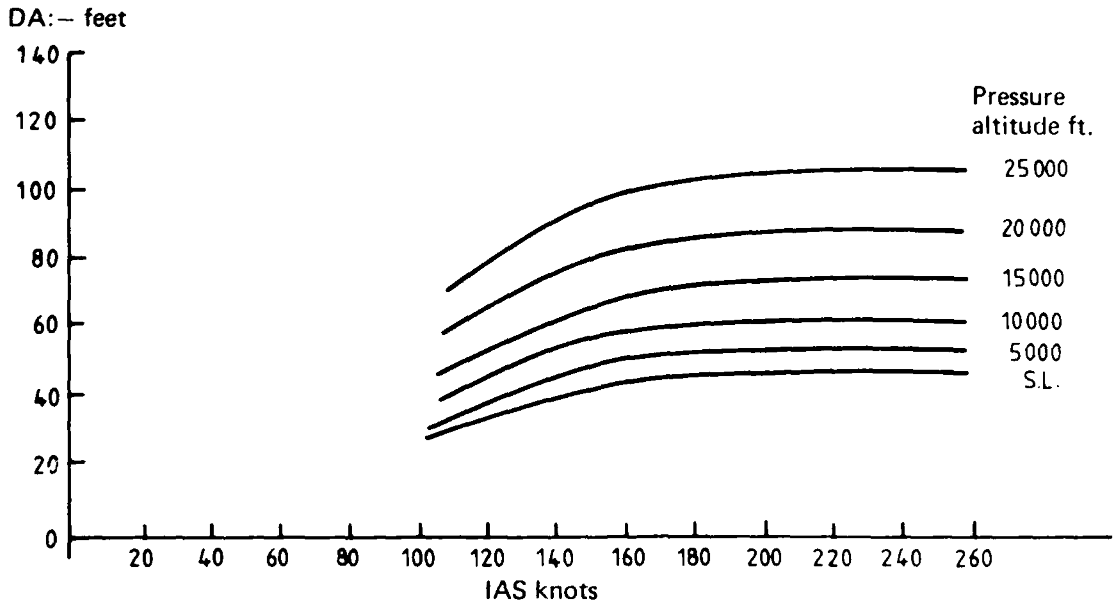

FIG 13(a) HS 748 AIRCRAFT PRESSURE ALTITUDE CORRECTION

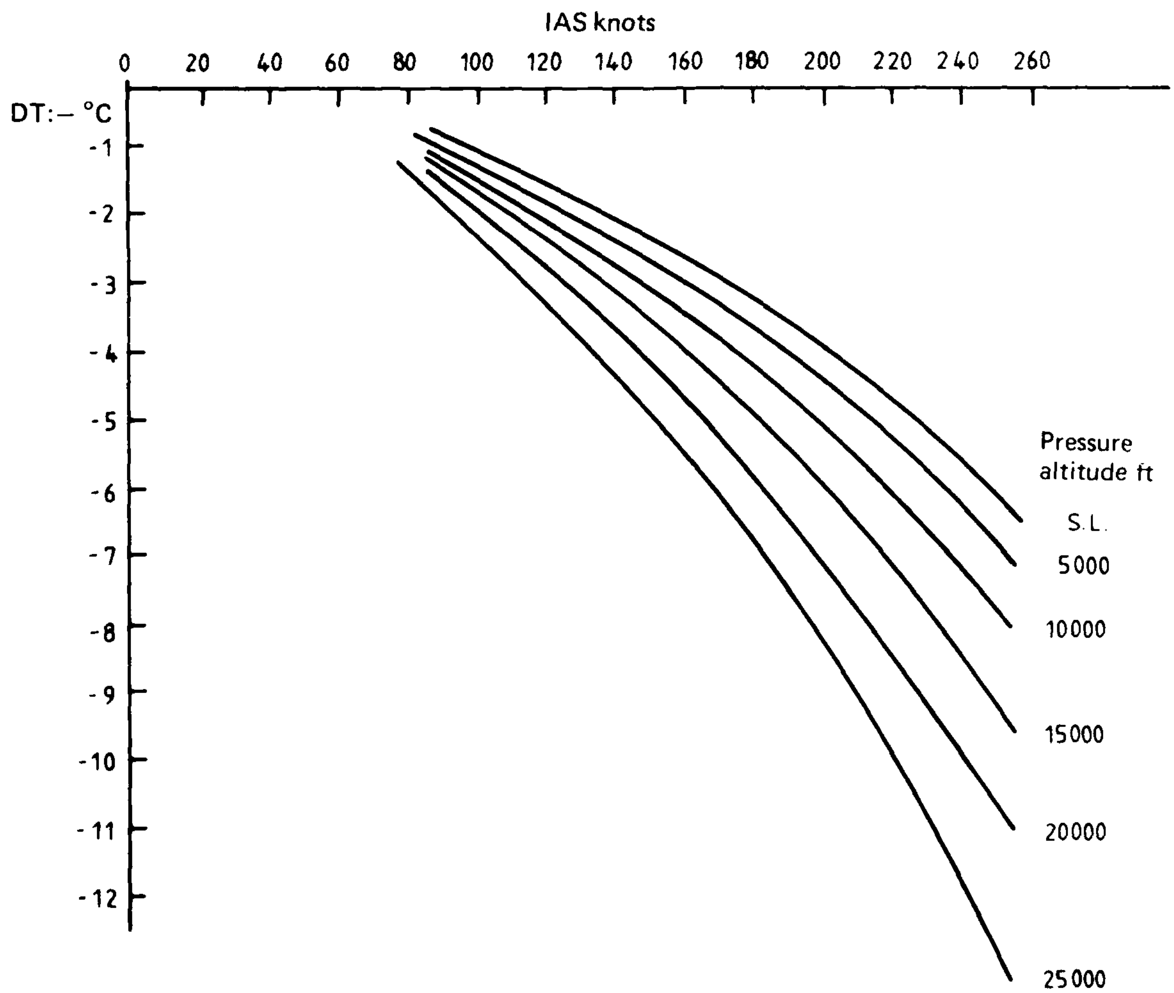

FIG 13(b) HS 748 AIRCRAFT INDICATED OAT CORRECTION

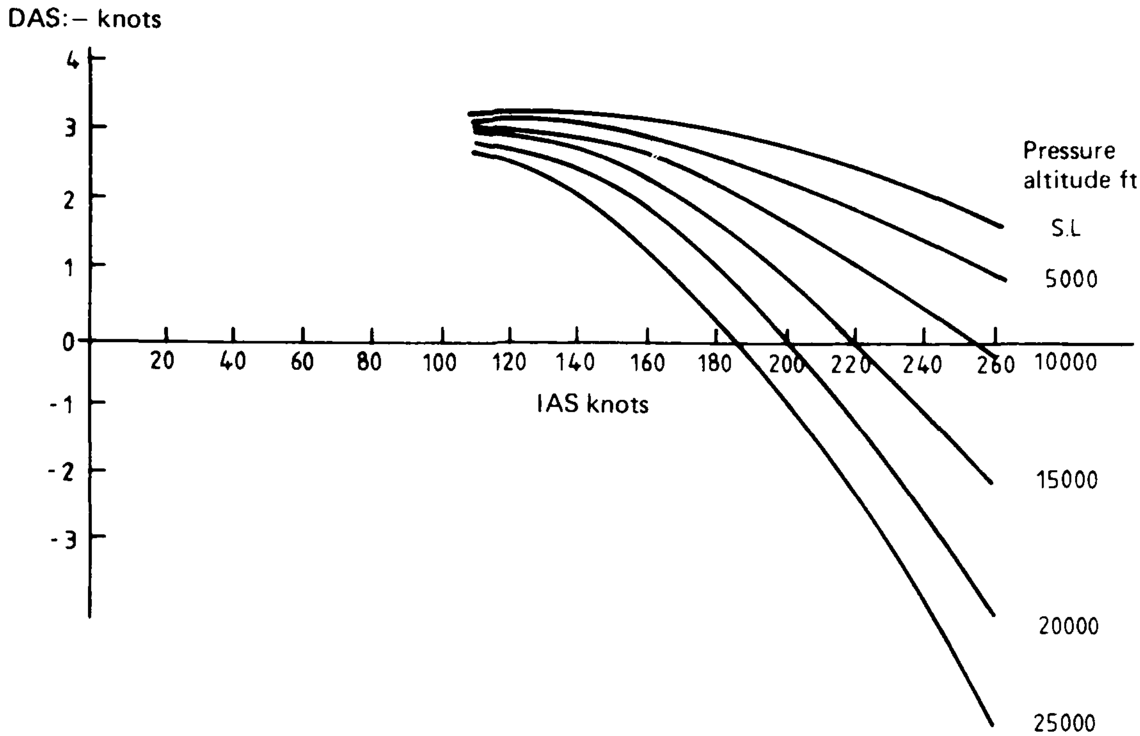

FIG 13(c) HS 748 AIRCRAFT INDICATED AIR SPEED CORRECTION

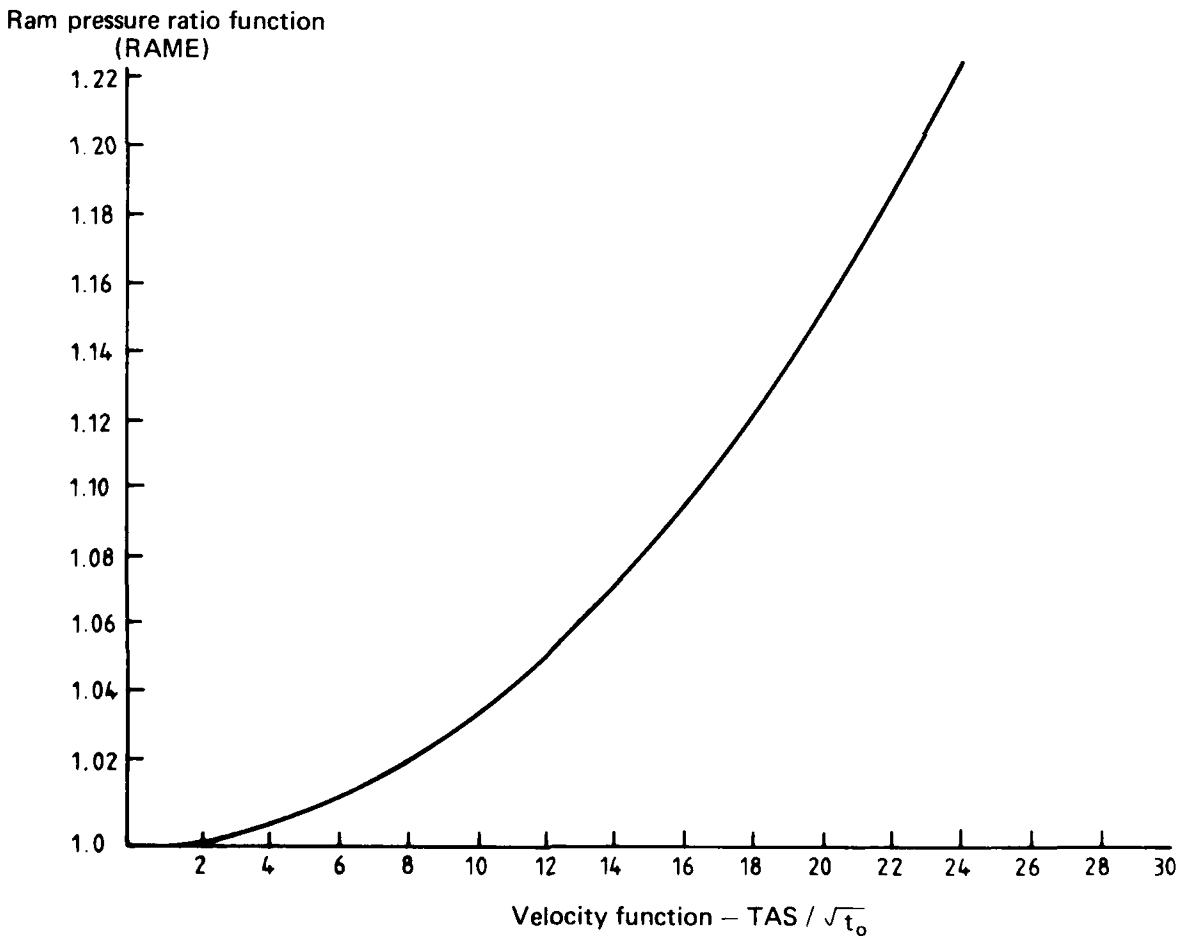

FIG 13(d) HS 748 AIRCRAFT INTAKE EFFICIENCY AND RAM RECOVERY FACTOR

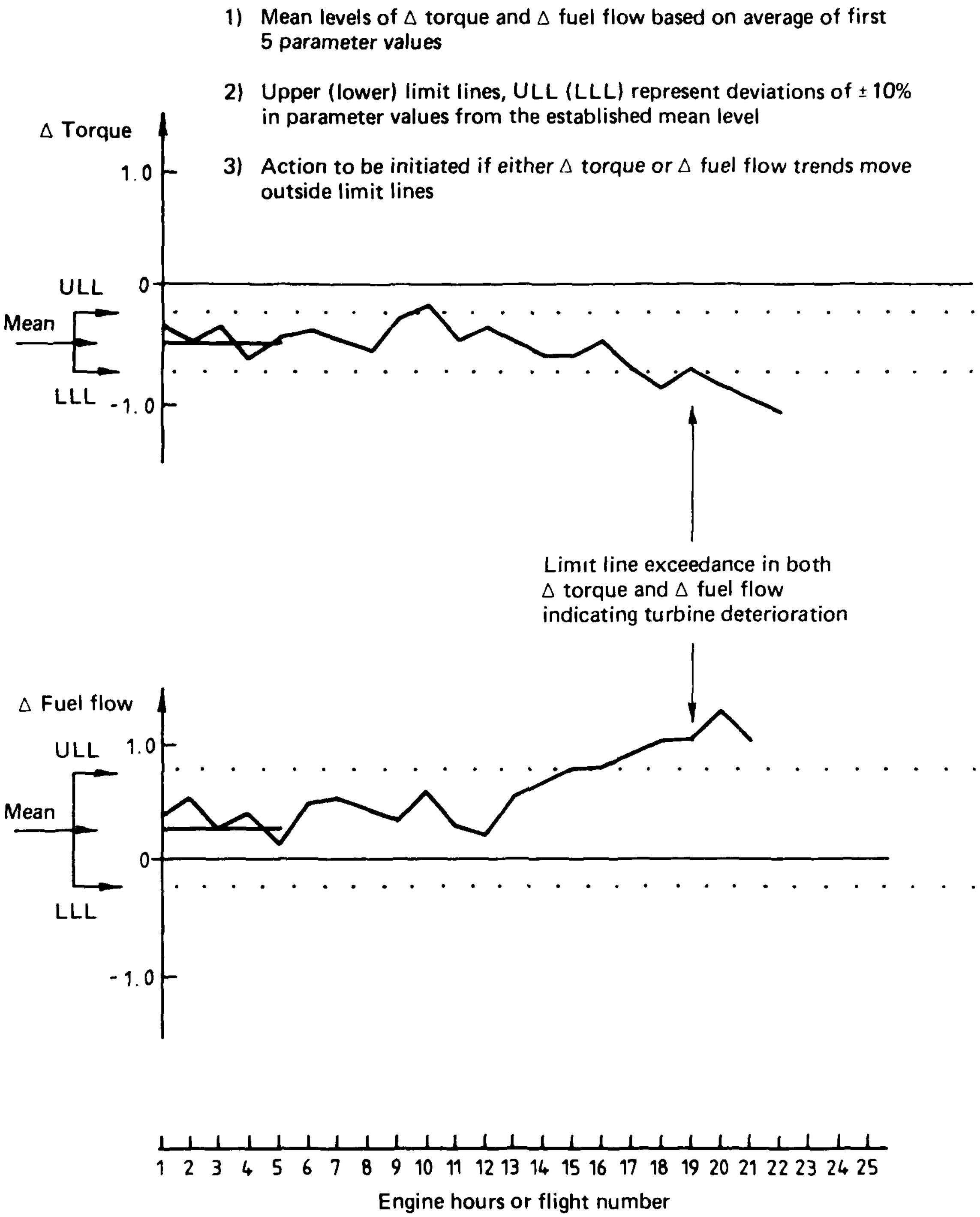

FIG 14 TYPICAL DART TORQUE AND FUEL FLOW TREND LINES

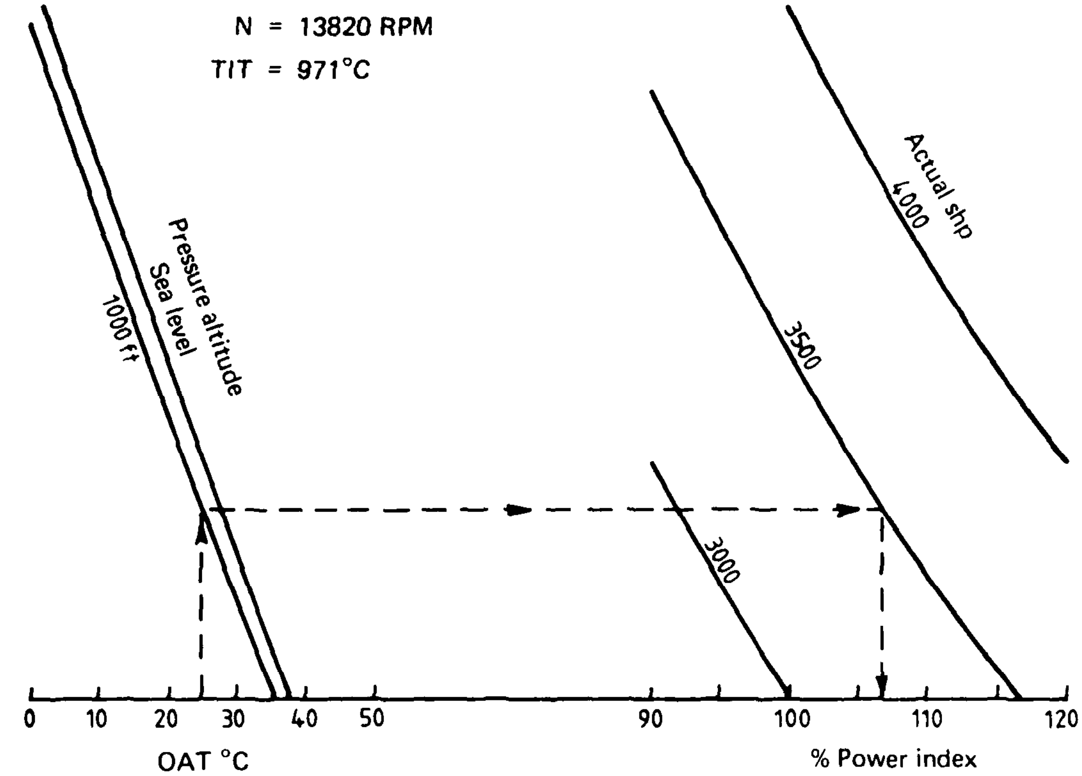

FIG 15 ALLISON 501-D13 INSTALLATION POWER CHECK

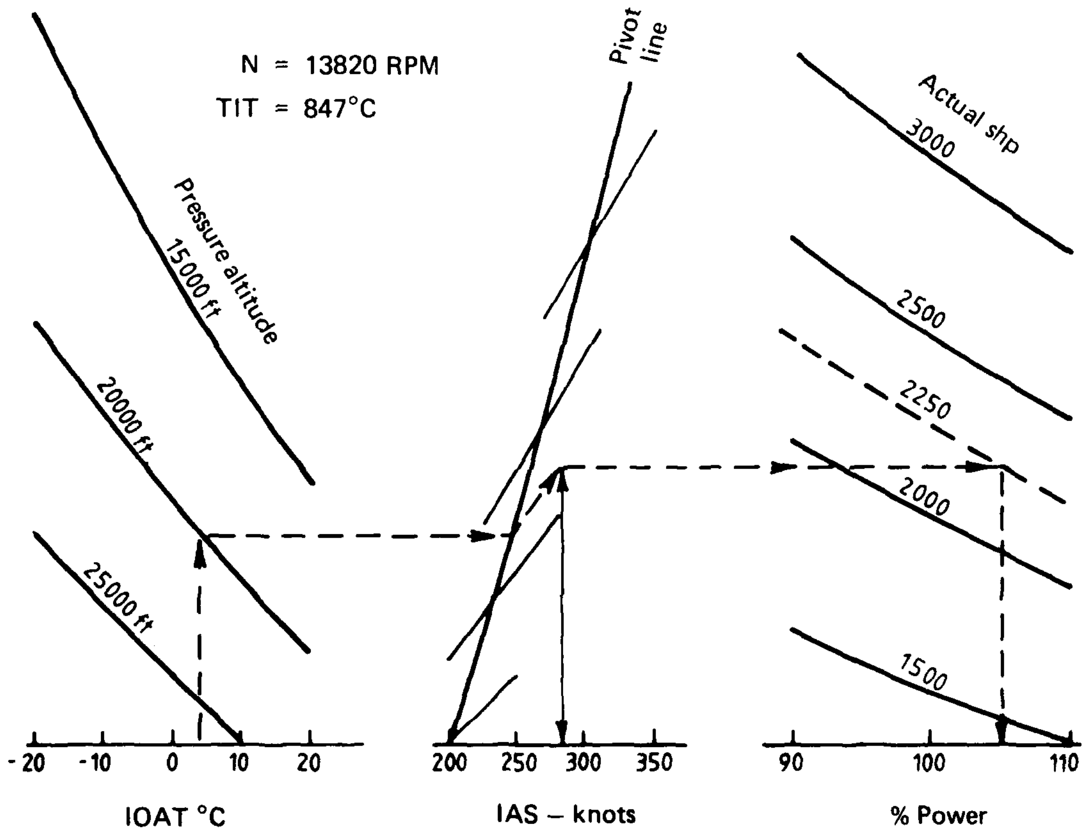

FIG 16 ALLISON 501-D13 CRUISE POWER CHECK

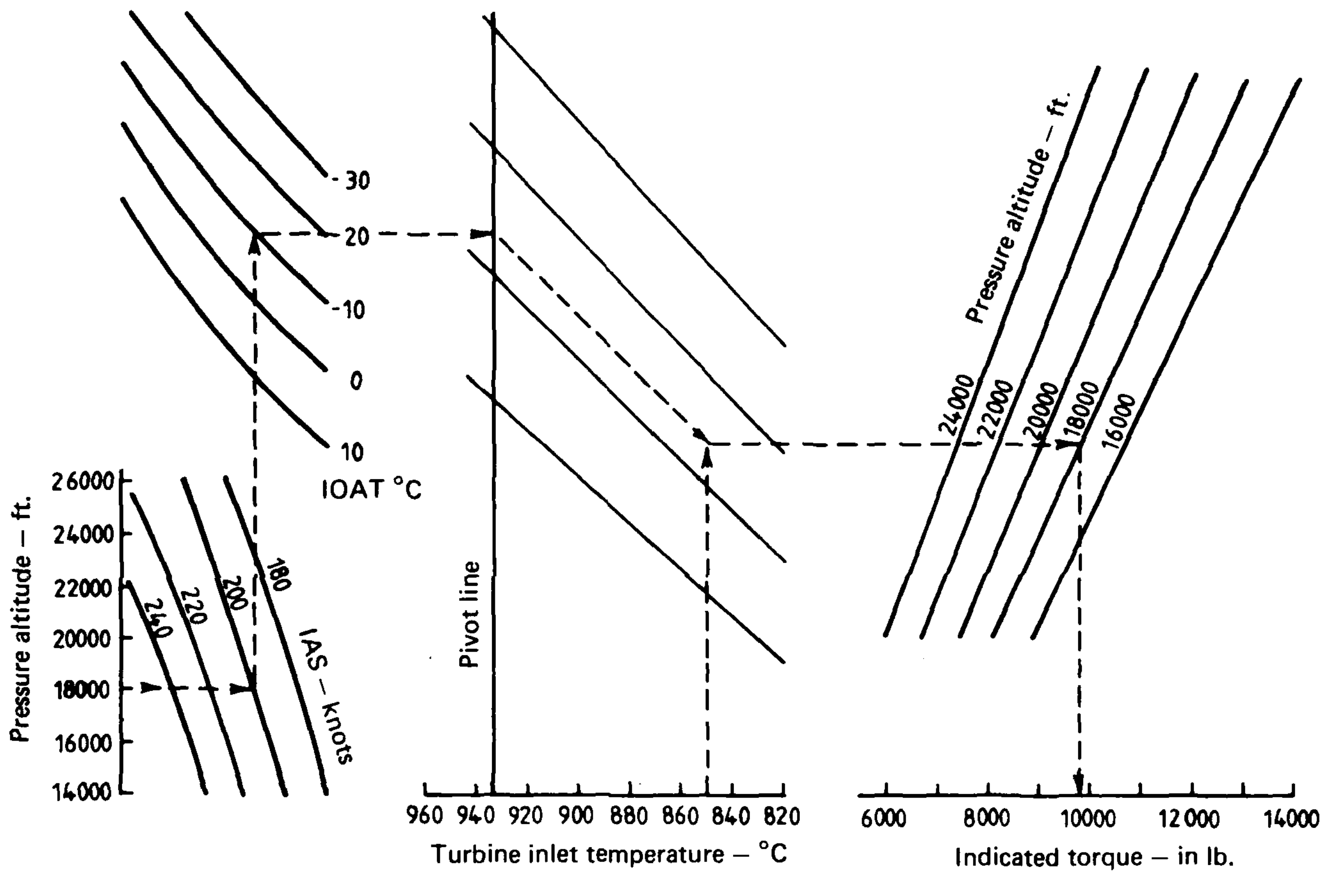

FIG 17 ALLISON T56-A-7 SPECIFICATION PERFORMANCE – TORQUE

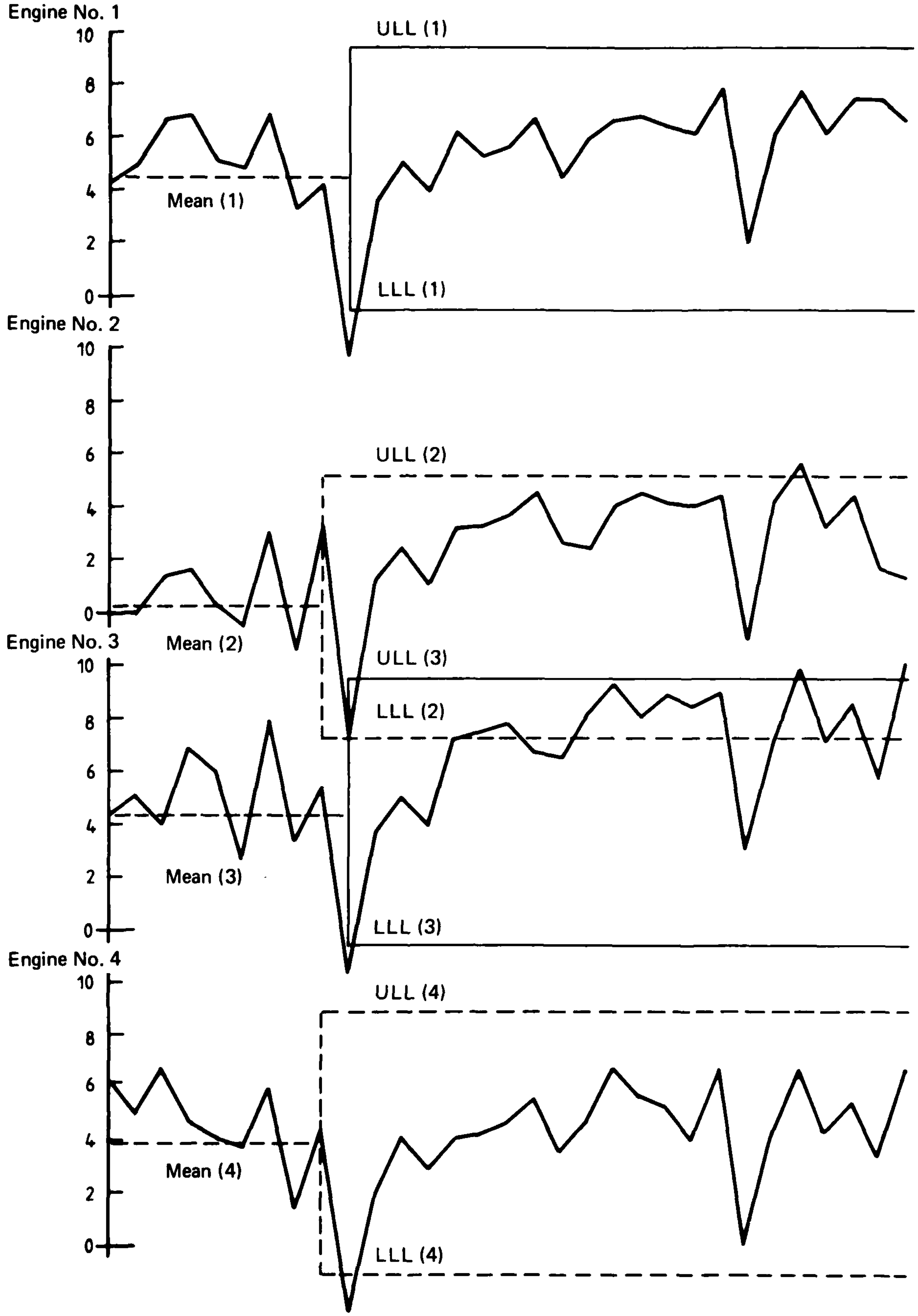

FIG 18 Δ TORQUE – % DEVIATION OF CORRECTED OBSERVED TORQUE WITH RESPECT TO ENGINE SPECIFICATION

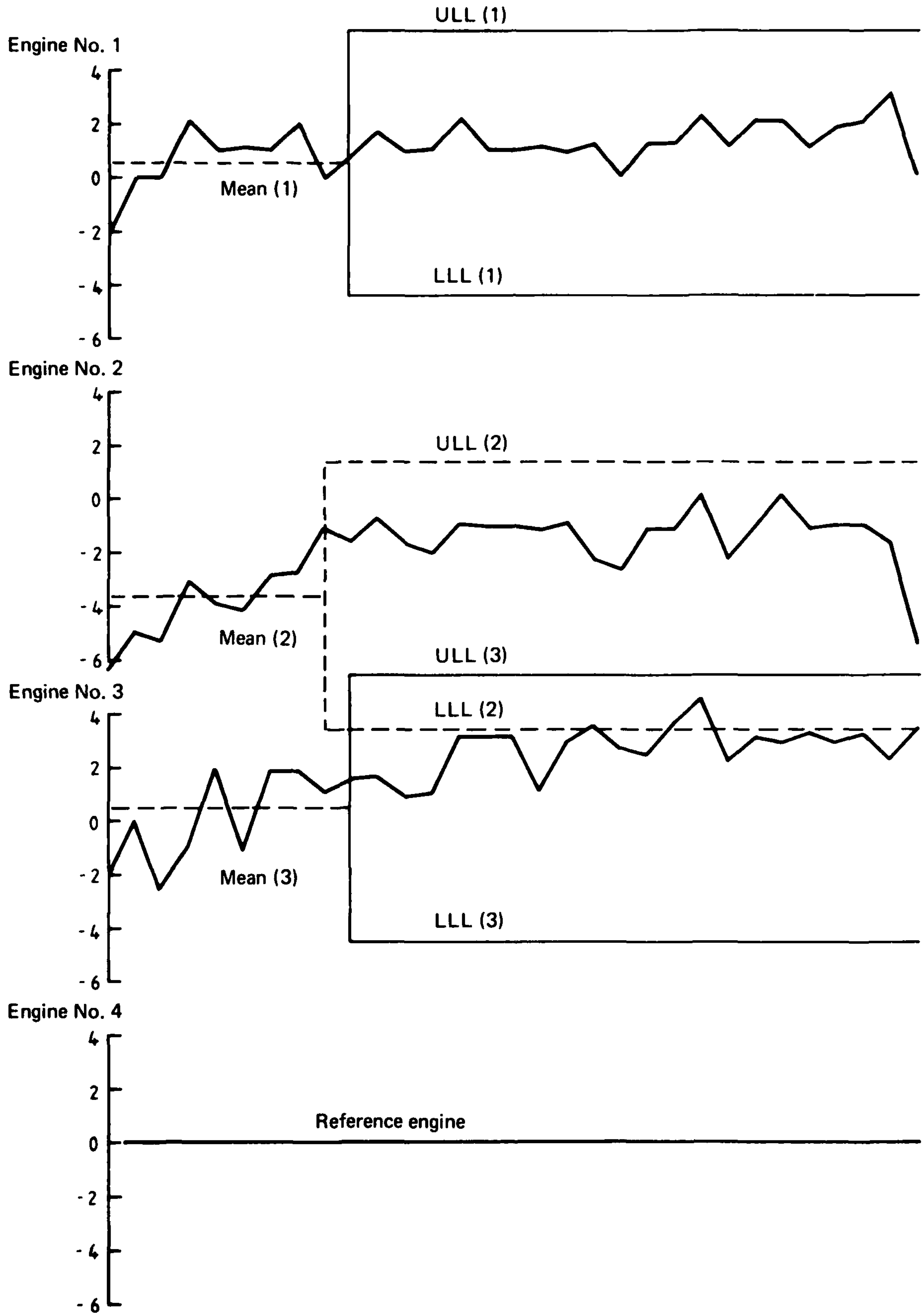

FIG 19 Δ TORQUE – DIFFERENCE BETWEEN CORRECTED OBSERVED TORQUES, ENGINE NOS. 1-3 MINUS ENGINE NO. 4

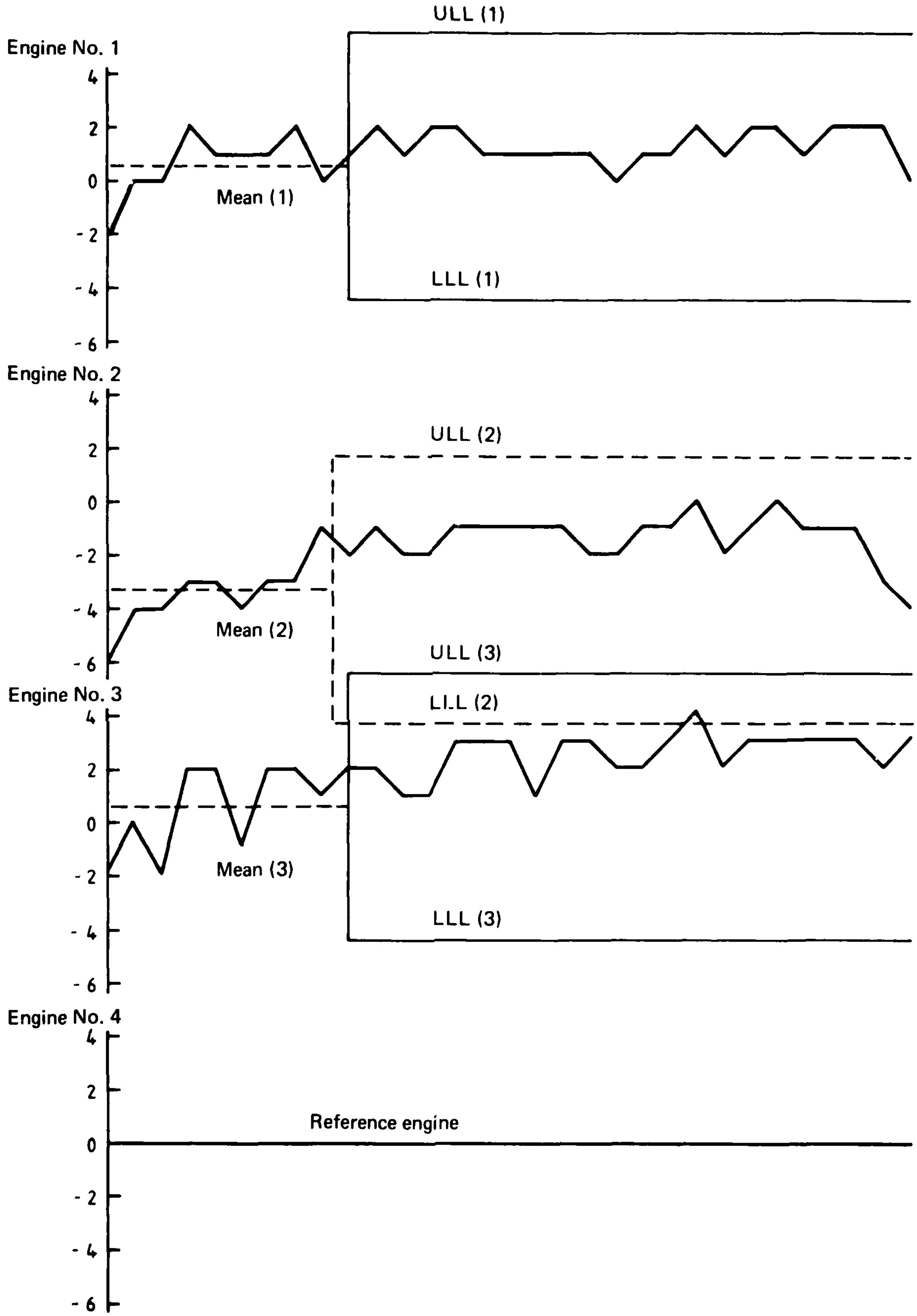

FIG 20 Δ TORQUE – DIFFERENCE BETWEEN OBSERVED TORQUES, ENGINES NOS. 1-3 MINUS ENGINE NO. 4

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Turboprop engines	Allison T56 engines	
Performance evaluation		
Engine performance monitoring		

16. Abstract

Two Manual Inflight Engine Performance Monitoring Procedures for use on turbo-prop engines have been devised. The first method, which involves relatively complex data reduction, is applicable in its present form only to the Rolls-Royce Dart engine. The second method, requiring only simple arithmetic calculations, may be used on any multi-engined aircraft. The basic principles and operating procedures for both methods are described.

Analysis of inflight engine performance data for the Dart, has shown that even though consistent results in terms of performance trends can be produced, the computational equipment and procedures required to derive the appropriate trend graphs are excessive and are considered not to be warranted or cost effective at present.

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16. Abstract (Contd)

With the second method, an analysis of trial data obtained from the Hercules C130–T56 aircraft has shown that effective engine performance monitoring trend plots, for both torque and fuel flow deviations, may be obtained. The simple data reduction procedures involved allow the relevant analyses to be carried out in flight by a flight engineer or suitable qualified person, thus giving immediate engine trend information for use by aircrew and maintenance personnel on a day-to-day basis.

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